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THIN FLOORS FOR BRIDGES.

By ALBERT F. ROBINSON, M. Am. Soc. C. E.

READ SEPTEMBER 7TH, 1892.

WITH DISCUSSION.

Much time and study have been given to designing the floors of our railway bridges. Notwithstanding this, the floor is the most usual source of weakness to-day. In most cases this weakness is due to an insufficient depth from base of rail to clearance line. The grade line is usually placed so near extreme high water that there is not room for a properly designed floor.

Ten or fifteen years ago the uniform moving load used was seldom more than 2 200 to 2 600 lbs. per linear foot of track, while at present it is 4 000 lbs. or more, and in addition the heavy concentrated loads due to engine drivers must be provided for. In spite of this great increase in the rolling load, the designers have seldom

been allowed to use the depth of floor they considered the best. For 14 ft. clear width of roadway, bridges having beams as much as 3½ ft. deep and stringers 2½ ft. or more in depth are not frequent. The increase in depth of floor can hardly be said to have been proportionate to the great increase of the rolling load.

The writer has examined bridges on main lines of railway having a heavy traffic, in which the floor beams were from 18 to 24 ins. deep over the flange angles, and had from one to three cover plates. The stringers were sometimes of wood and sometimes of rolled beams. The deflection of the beams and stringers in these structures was so great that the rivets connecting the beams to the posts could not be kept tight, though redriven frequently (in one case twice within a year). This excessive deflection in the floor must cause a motion in the trusses, which is injurious, and will greatly shorten the life of a structure, notwithstanding the fact that the trusses themselves are reasonably well designed.

In and near our large cities, where grade crossings are gradually being abandoned and tracks elevated or depressed, the depth of the bridge floor is of great importance. Every inch saved in the floor reduces the cost of the approaches to the bridge, the amount of abutting damages on account of elevating the track, and the extra cost of operating the road due to the increased grade. As a result many of the overhead bridges in our cities have very shallow floors which do not stand at all well under traffic. The rivets connecting the stringers to the beams, and the beams to the posts (when beams are riveted between posts), are continually getting loose. Any small defects are aggravated by this floor, and the structures are apt to need extensive repairing in a few years after erection; and this will make the maintenance charges high.

Many different kinds of shallow floors have been tried, but with somewhat indifferent success. They may carry the traffic, but soon get out of repair, and are very liable to fail in case of derailment. One of the most satisfactory thin floors yet used has been of heavy timber ties which carry the load from the rails directly to the main trusses or girders. In through plate girders these ties rest upon shelf angles placed as near the bottom flange angles as possible. In lattice girders or short through truss spans they are suspended from the bottom chords by bolts, as in some of the bridges on the Buffalo extension

of the Lackawanna road. These floors must necessarily be short lived, since they depend entirely upon the strength of the timber ties; they will also be expensive and inconvenient when renewals are necessary.

Under the above circumstances the writer may be warranted in the assertion that no very thin bridge floor, which will meet all ordinary requirements, has yet been brought before the engineering public. Our problem, then, is to design the thinnest possible bridge floor which will comply with the following requirements:

First.—It must be reasonably low in first cost, and must be long lived.

Second.—It should not be liable to fail under derailment, and, if possible, it should be able to stand under collisions.

Third.—The erection must not be unreasonably inconvenient, and the floor should be so arranged that it can be put in without interrupting traffic.

Fourth.—It should show low cost for maintenance, and be so arranged that the ties can be renewed without serious expense or the interruption of traffic.

Fifth.—It must not attract the unfavorable criticism of passengers by the way it carries a train.

Sixth.—It should please trainmen and gain their confidence by its appearance of strength and ability to stand hard continuous service.

Some time in 1887, George S. Morison, M. Am. Soc. C. E., used a 12-in. Lindsey floor for the Willamette River bridge, in which the ties were about 12 ins. deep. In this structure the distance from base of rail to clearance line was about 2 ft. In 1889 the writer, then in the employ of E. L. Corthell, M. Am. Soc. C. E., designed the bridges for the crossing of the Chicago, Madison and Northern Railway over the Chicago, Burlington and Quincy Railroad and three streets in the town of Clyde, near Chicago. He used a solid steel floor having a distance of about 18 ins. from base of rail to clearance line. The metal work of this crossing (known as the "Clyde Viaduct") consisted of three 60-ft. through plate girders and two pin-connected spans of 161 and 148 ft. 6 ins. respectively. In the trusses 24-in. stiff bottom chords were used; the floor throughout was 12 ins. deep over covers and made up of plates and angles. The cross-ties rested upon brackets in the troughs. This floor rested

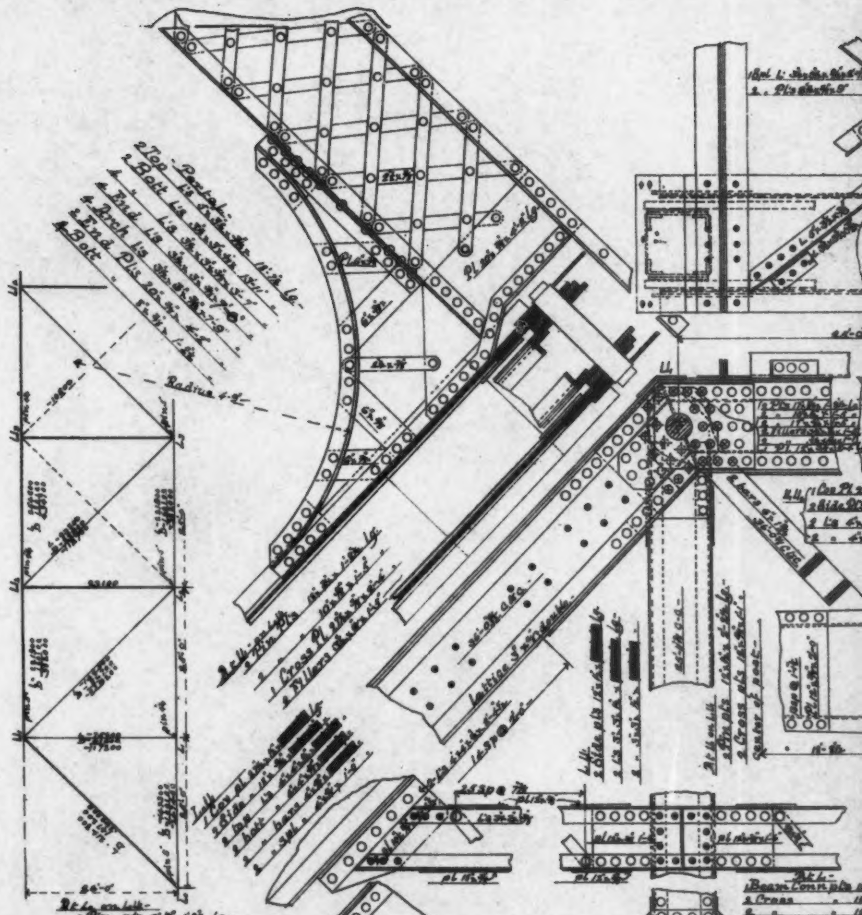
upon shelf angles which were riveted to the webs of the plate girders and stiff bottom chords, as close to the bottom flange angles as possible.

The troublesome points developed in the shopwork and erection of these bridges, together with the knowledge gained thereby, and the continuous calls upon the writer for a still shallower floor, caused him to begin the study which has resulted in the partial set of plans accompanying this paper. They are carried only far enough to show clearly what is necessary for the paper in hand, and can not be called finished. G. H. Thomson, M. Am. Soc. C. E., bridge engineer for the New York Central and Hudson River Railroad, has for several years been using the same bridge floor as the one here presented, but he has used it with lattice girders and ballast.

The writer is not prepared to advise the use of a solid floor (with or without ballast) for all short spans and all classes of traffic, as the expense will be comparatively large, and a properly designed deep floor with timber decking in good order is fairly secure. He believes the time will soon come when wooden cross-ties will be abandoned on all metallic bridges, and that all short spans will have solid floors, though not necessarily covered with a layer of ballast. In bringing this floor before the Society for its criticism, faults will doubtless be discovered, possibly grave ones; but the writer trusts that the paper may be found worthy of careful discussion and feels certain that no engineer will find the time "wasted" which he devotes to the study of thin floors.

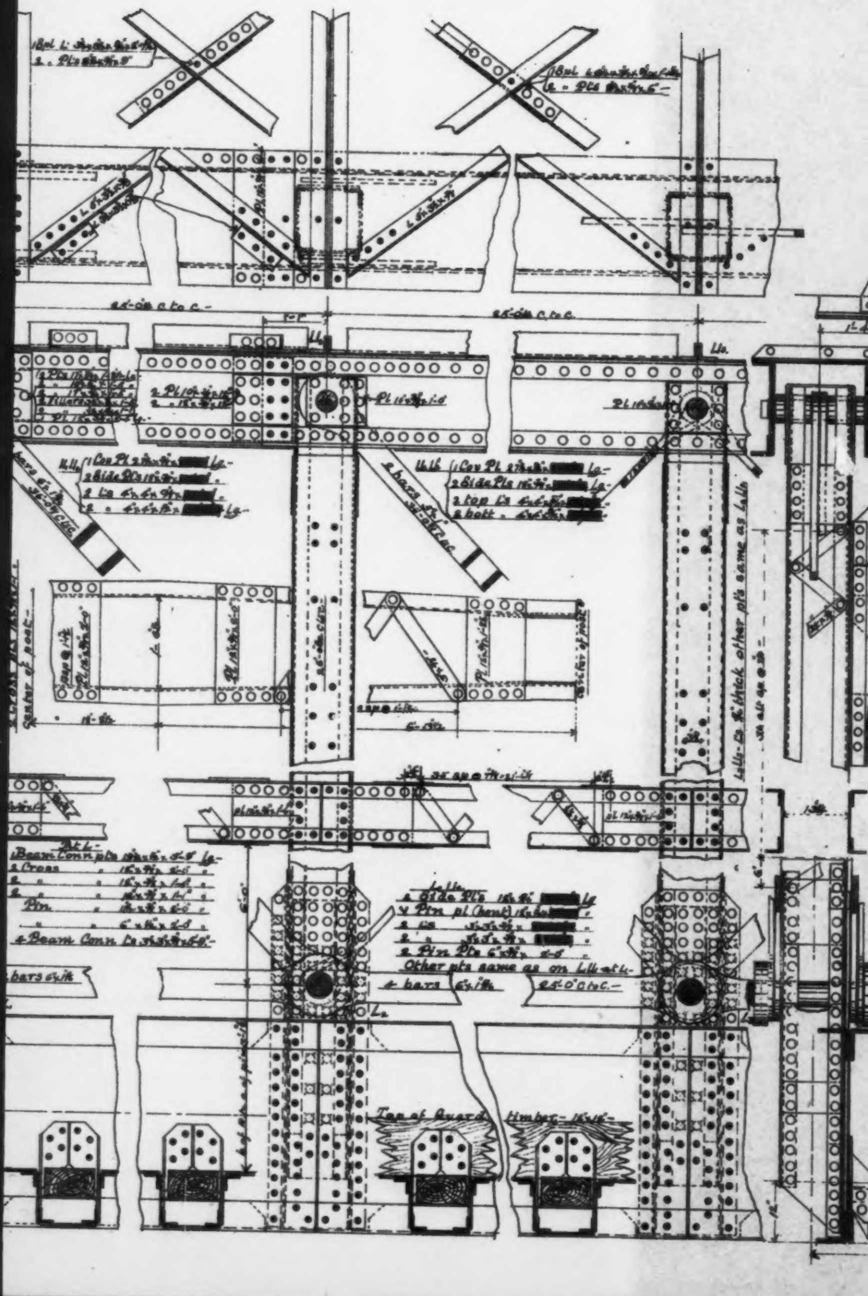
Description of Plans.—We will now pass to a description of the proposed plans and a discussion of the same. Plate LXI gives the general elevation of a 150-ft. truss span, with details of connections, laterals, portals, etc. Plate LXII shows the stringers, pedestals, bed plates and expansion rollers. Plate LXIII shows the box floor complete for the full span, together with the sub-pedestals, really a part of the floor. Plate LXIV shows a 48-ft. through plate girder span, with floor and bed plates complete. In both of these the extreme distance from base of rail to clearance line is 12 ins.

Discussion of Plans.—Mr. Thomson in his practice has used plate and lattice girders almost entirely. The details will generally be about the same in lattice spans as in the plans proposed, whether they be used with ballast or without. In passing, the writer would say that



2 Top Portal-
Radius 4-9
Lattice
center of post-
2 bars
Pin
Beam Conn pls
4 Beam Conn
1 Cross
2 Fillers
Stringers.-
Max Load- 120950 lbs
Flange Stress 114000-

ROBI



25'-0" c. to c.
Top of Guard Timber
Other pl's same as on L_4 at L_5
Center of post

PLATE LXI.
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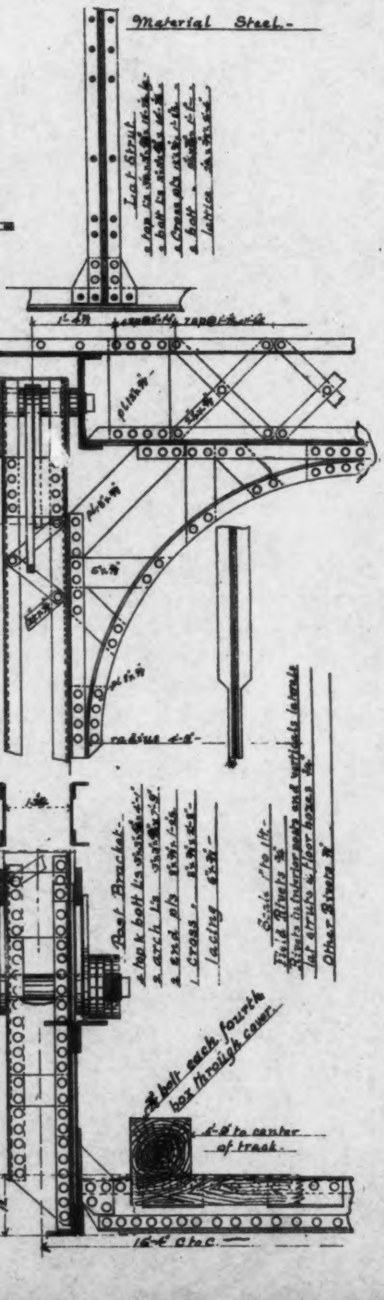
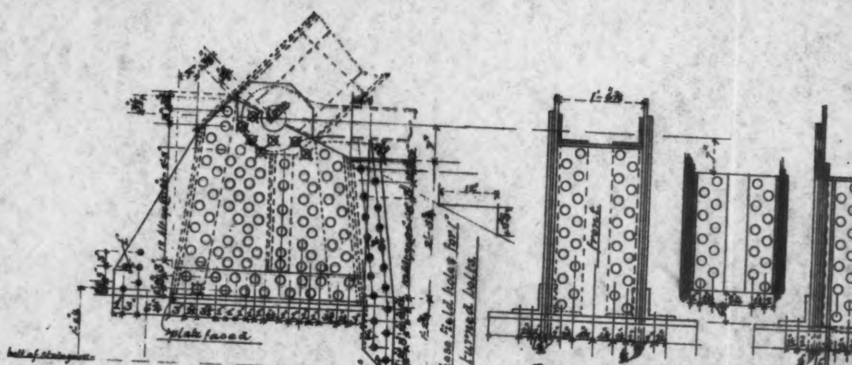
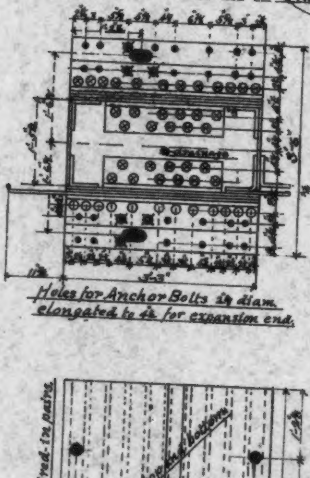




4 Pedestals Required - in pairs -

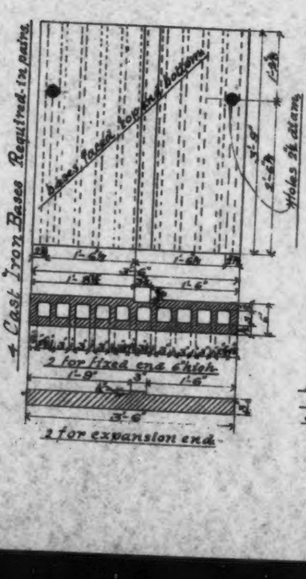


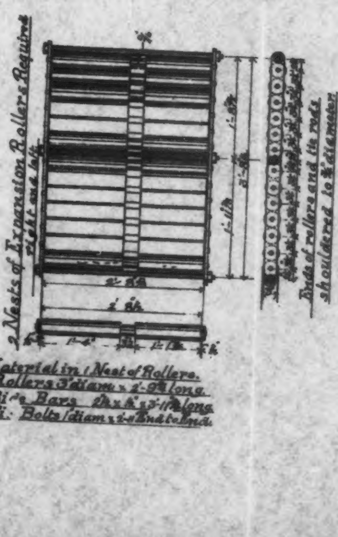
Holes for Anchor Bolts 1¼ diam. elongated to 4½ for expansion end.

Material -

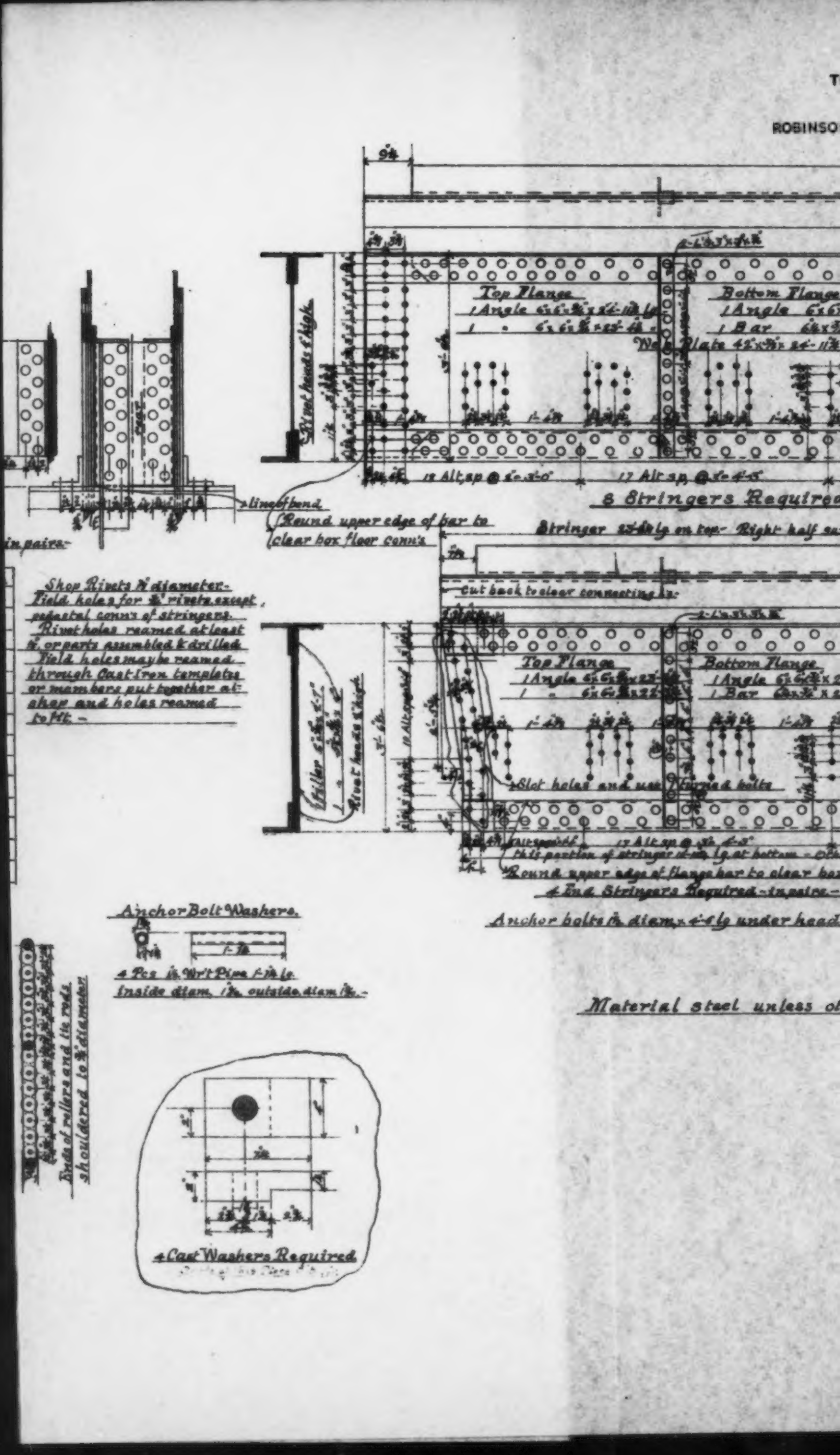
4 Bottom Pls 39"	39" x 1" x	3'-6" lg
4 Side " (about)	40¾ x 9/16	4-2½ "
8 " " "	39" x 9/16	3'-8" "
12 " " "	39" x 9/16	3'-1½ "
4 End Web Pl's	16¾ x ½	2-10 "
4 " " "	16¾ x ½	2'-6" "
4 Mid " "	16¾ x ½	1'-11½ "
4 Bent angle plate	13½ x 1(6 x 7½)	2-8½ "
4 Str Conn "	12½ x ½	2'-8½ "
8 Bottom " L's	6 x 6 x ¾ x	3'-3" "
8 " " "	6 x 6 x ¾ x	2'-0" "
8 End Conn L's	6 x 6 x 5/8	3-4½ "
4 " " "	6 x 6 x ½	2'-8½ "
4 Str Conn L's (bent)	6 x 6 x ½	3'-6½ "
8 Web Conn L's	6 x 4 x 5/8	1'-11½ "

Shop Rivets ...
Field holes fo...
pedestal conn...
Rivet holes ...
¾, or parts asse...
Field holes ...
through Cast ...
or members p...
shop and ho...
to fit -





Material in 1 Nest of Rollers.
13 Rollers 3" diam x 2'-9⅞ long.
2 Side Bars 2½ x ⅝ x 3'-11⅝ long
3 Tie Bolts 1 diam x 2'-8 End to End.



ROBINSO
Top Flange
Bottom Flange
Web Plate
Rivet heads ⅝ high
line of bend
Round upper edge of bar to clear box floor conn's
8 Stringers Required
Stringer
Right half
in pairs-
Shop Rivets ⅞ diameter. Field holes for ⅞ rivets except pedestal conn's of stringers. Rivet holes reamed at least ⅛ or parts assembled & drilled. Field holes may be reamed through Cast Iron templets or members put together at shop and holes reamed to fit.-
Cut back to clear connecting
Top Flange
Bottom Flange
Slot holes and use turned bolts
This portion of stringer
Round upper edge of flange bar to clear box
4 End Stringers Required-in pairs-
Anchor Bolt Washers.
4 Pcs Wr't Pipe
Inside diam. outside diam.
Anchor bolts diam. under head
Ends of rollers and tie rods shouldered to ¾ diameter
Material steel unless ot
4 Cast Washers Required

PLATE LXII.
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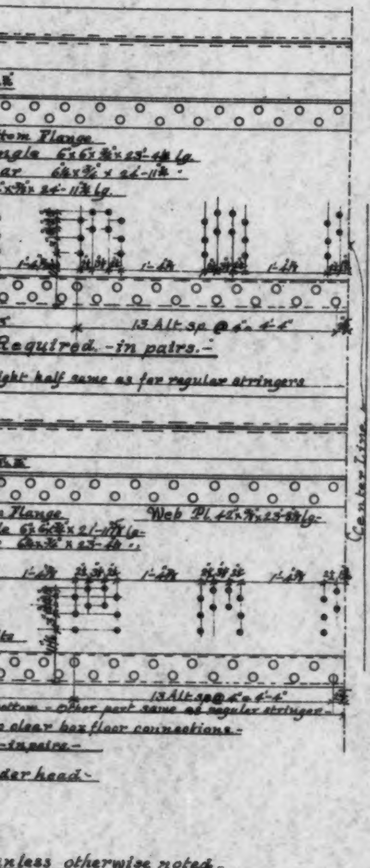
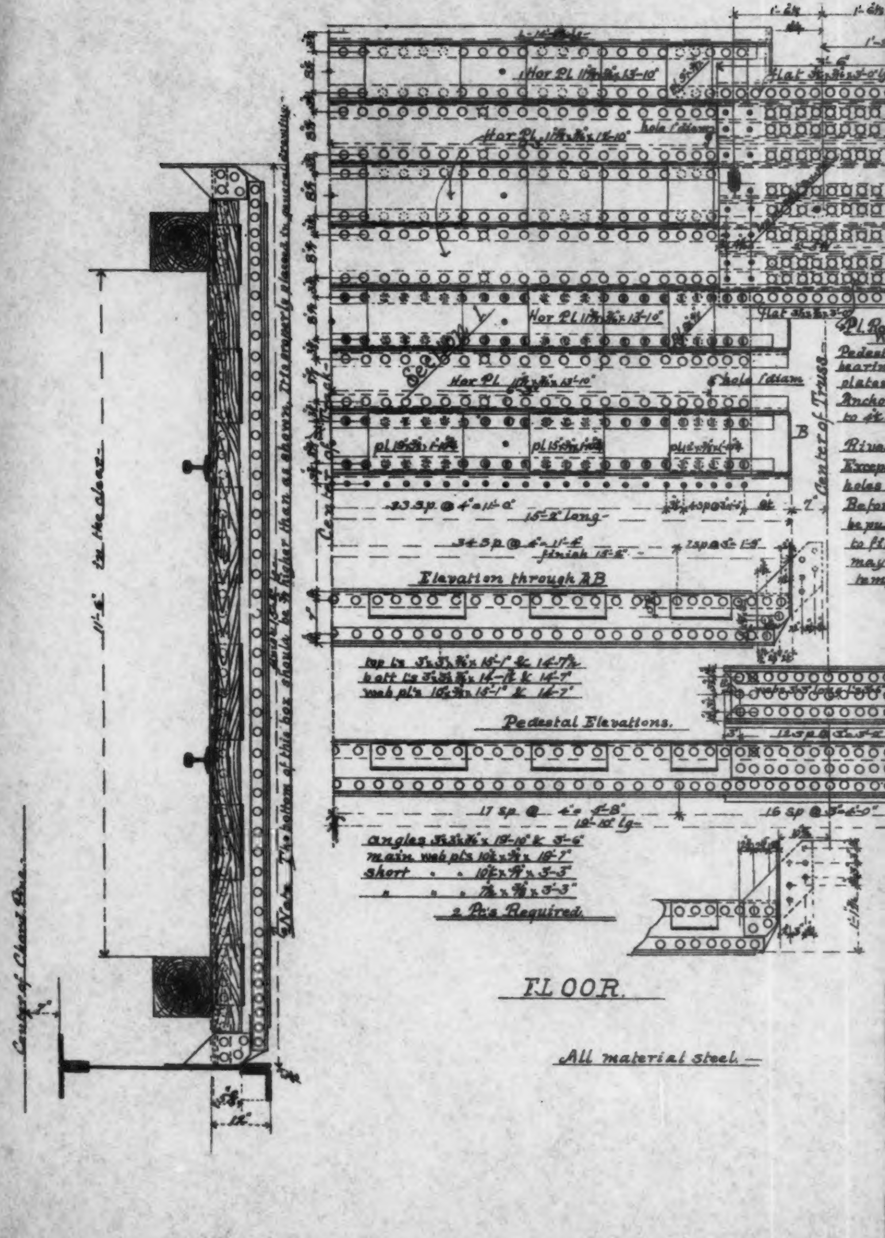
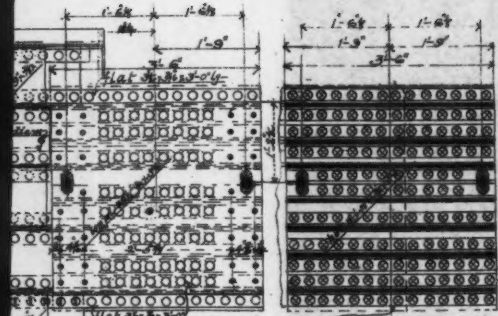
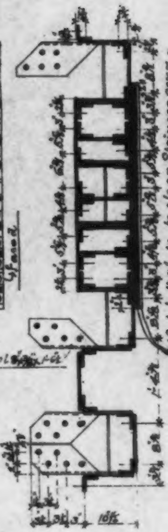


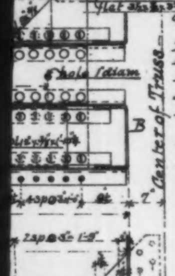


FLOOR.

All material steel. —



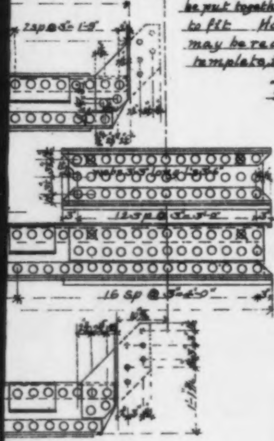




Pl. Roughfaced.
Web Plates in Pedestals have full bearing against bar plates & angles top & bott.
Anchor Bolt holes 2¼ diam. elongated to 4¼ at Expansion End.

Rivets ⅞ diam.
Except where otherwise noted, field holes punched for ⅞ rivets.
Before shipping the sections shall be put together and holes reamed to fit. Holes in end connections may be reamed through cast iron template, if desired.

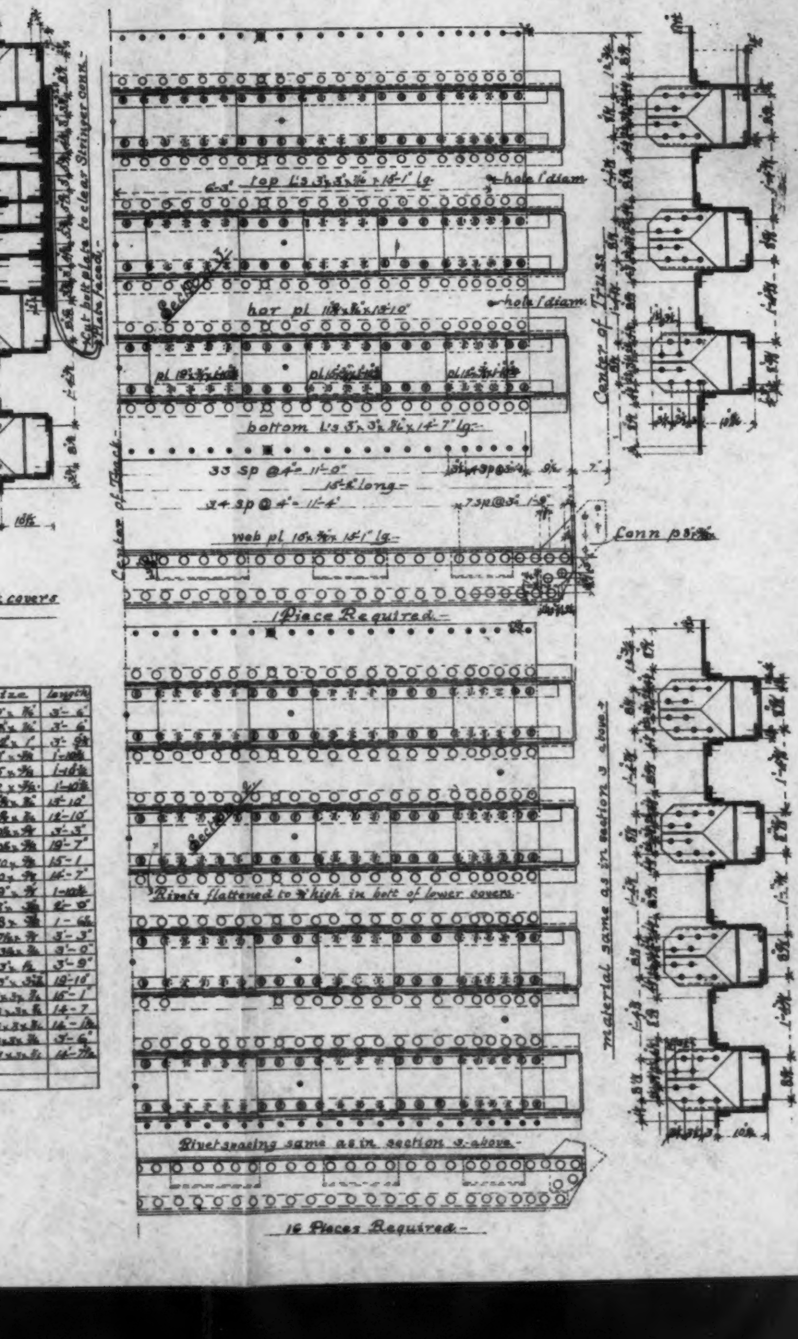
Notice Rivet heads in bottom of bolt covers must not project over ⅜ below covers.

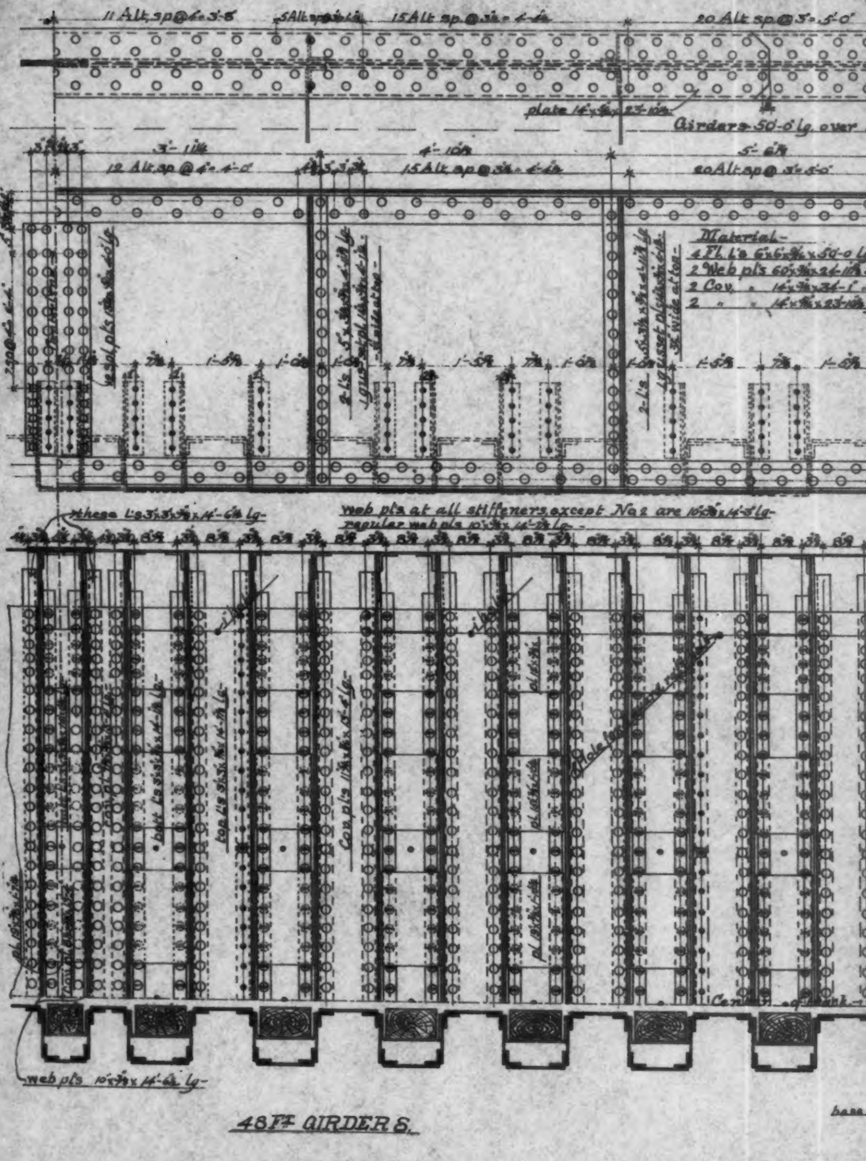


Material

Number Pieces	Description	Size	Length
4	Top Plates	38" x ⅞"	3'-6"
4	Bottom "	38½ x ¾"	3'-6"
4	Sole "	42 x 1	3'-9[illegible]
150	Tie supporting plates (bent)	18" x 5/16	1'-10[illegible]
150	" " " "	16 x 5/16	1'-10[illegible]
138	" " " "	12 x 5/16	1'-10[illegible]
143	Cover Plates	11¾ x ⅜	15'-10"
6	" "	11¾ x ⅜	12'-10"
12	Web "	10½ x ¾	3'-3"
8	" "	10½ x ⅜	19'-7"
140	" "	10 x ⅜	15'-1
2	" "	10 x ⅜	14'-7"
12	Tie supporting plates (bent)	9" x ⅜	1'-10[illegible]
4	End connecting plates (bent)	8 x ⅜	2'-0
280	" " " "	8 x ⅜	1'-6[illegible]
24	Web Plates	7½ x ⅜	3'-3
4	Fillers	3½ x ⅜	3'-0
4	Guide Bars	3 x 1½	3'-9
16	Flange Angles	3 x 3½	19'-10"
140	" "	3 x 3 x ⅜	15'-1
140	" "	3 x 3 x ⅜	14'-7
2	" "	3 x 3 x ⅜	14'-[illegible]
44	" "	3 x 3 x ⅜	3'-6
2	" "	3 x 3 x ⅜	14'-7[illegible]

al steel. —


hole 1" diam.
hole 1" diam.
Center of Truss
Center of Track
15'-6" long
web pl
Conn pl
1 Piece Required.
Rivets flattened to high in belt of lower covers.
Rivet spacing same as in section 3 above.
material same as in section 3 above.
16 Pieces Required.
Cut bolt plate to clear Stringer conn.
covers
size
length



48 Ft GIRDERS.

All material, except cast bases, Steel.
Rivets-7/8" in main girders-3/4" in box floor & 7/8" for all field rivets.
Holes reamed or drilled in the solid, in main girders-
Field holes reamed to fit, or through cast templets.-

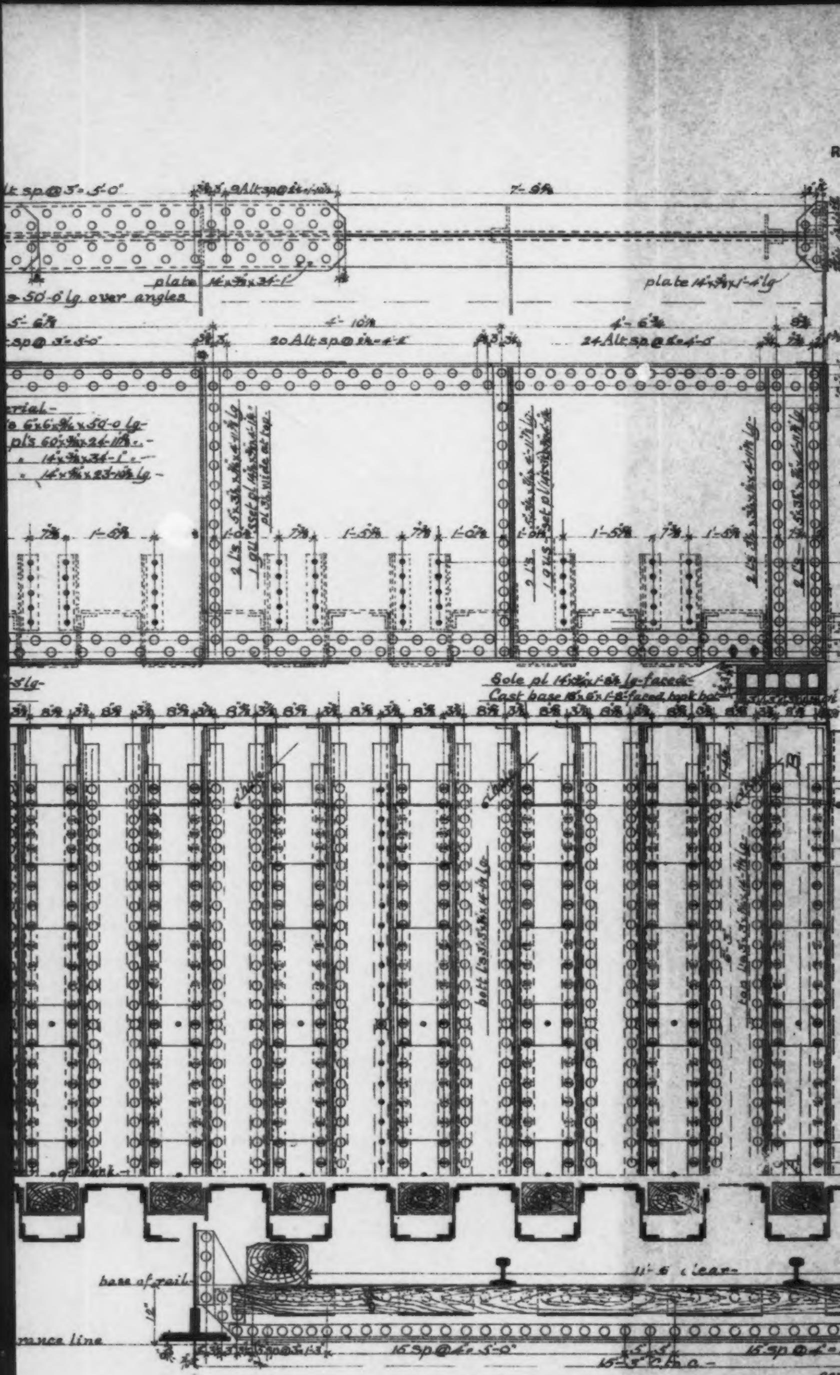


plate 14x3/8x34-1'
plate 14x3/8x1'-4 lg
Sole pl 14x3/4x1'-8 lg-faced
Cast base
base of rail
11'-6 clear
15 sp @ 4 = 5'-0"
15-3" C to c.-

PLATE LXIV.
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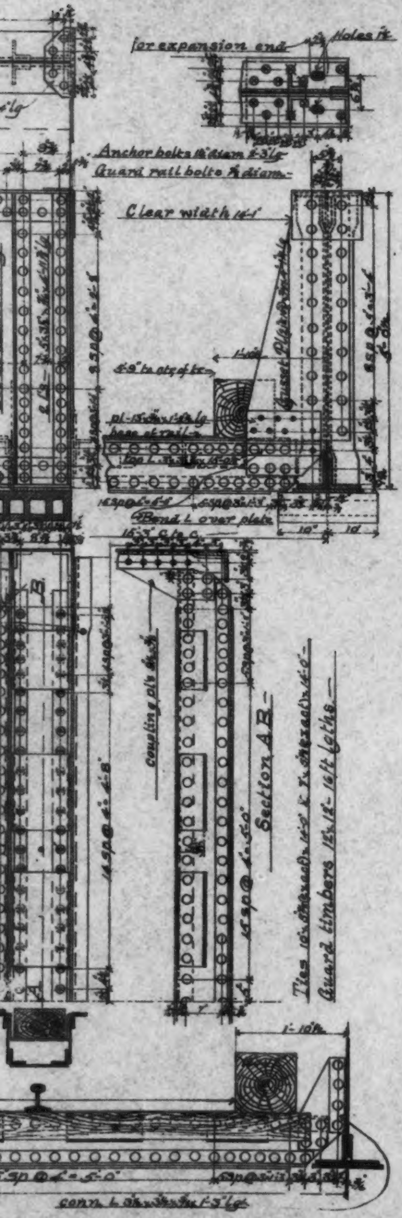


in lattice spans much trouble will no doubt be found in making the rivet holes, which connect the box floor with the bottom chords, coincide with the regular rivet spacing in these chords. This is especially the case at the panel points, where the web members must also be cared for. Without attempting in any manner to detract from the great merit of the lattice girder, which the writer fully recognizes, he has undertaken to adapt this thin floor especially to pin-connected spans and plate girders, believing this to be a comparatively new field.

One item in the faith of those who believe in pin-connected spans for nearly all except very short trusses, is that a pin-connected bridge can be made fully as secure in case of a derailment as a lattice span of the same approximate length and weight. In the plans under discussion the writer has attempted to make a span which will meet this requirement. With deep stringers, long panels and a solid floor, the two types should show but little difference in rigidity. Under derailment, one of the best features in lattice spans is the strength gained by the riveted intersections of the web members, no one member ever being left to its own resources in case of attack. In the present plan this is attained by the lines of horizontal struts extending the full length of both trusses, and by the stringers, which give the advantages gained by a stiff bottom chord. These horizontal struts also act as guards, keeping derailed cars from striking the web members, and they also take the place of collision braces at the end posts. The two lines of struts will probably not cost more than $4 per linear foot of bridge; the weight will be about 110 lbs. per foot.

The bridge is designed mainly in accordance with Mr. Theodore Cooper's specifications, and for the rolling load used by the Lehigh Valley Railroad. The material used is generally medium steel, made by the open hearth process. In the plans under discussion, the main items for comparison with other bridges are as follows:

First.—The trusses can be assembled and coupled up as quickly and easily as any ordinary pin-connected work, and can be made fully as secure in case of sudden loss of the false work.

Second.—The floor of the truss span can be put in without interrupting traffic any more than is done for ordinary floors, and without any more danger of accident. Holes for the anchor bolts are not drilled in the stone work until after the trusses are coupled up and the floor put

in place. The end or abutment sections of the floor must be placed before the pedestals. After the top lateral system has been put in and bolted up, the trusses can be spread enough at the bottom to allow the floor sections to swing in between the stringers from below. The pedestal can be made to slide easily upon the end sections of the box floor already placed. With proper management there need be no interruption of traffic, as the false work, carrying the tracks, can be taken out one panel at a time, and the floor put into place between ordinary trains. With plate girders, the better plan will be to erect the span complete, on light false work, at one side of the track, and then to slide the span over into position. This need not interrupt traffic. The floor can, however, be put in just as the false work carrying the track is removed, by rocking the tops of the girders outward a little and slipping the floor in from above.

Third.—The bridges in the "Clyde Viaduct" were finished early in the summer of 1890. The stiff bottom chords of the truss spans required a large number of field rivets in the splices, and the floor was hard to crowd into place. The bottom of the trusses, at mid-span, had to be crowded outward some 5 ins. to let the floor in. This work, erected and painted, cost about 4½ cents per pound; the erection and one coat of paint costing the railroad company seven-tenths of a cent per pound. Judging by the above, the writer feels justified in claiming that the pound price will never be more than for ordinary work.

Fourth.—All field rivets can be well driven, none being so located as to make heading or backing-up at all difficult. The field rivets are all ¾ in. in diameter and are generally short. Under the head of "Field Riveting" it may be well to note the increased number of field rivets per foot of bridge, due to the solid floor, and also to compare the total number per foot of span with those in a few lattice girders of which the writer has a record.

In the truss span there are 24 field rivets per foot of bridge; in the box floor and its connections with the stringers there are 15 field rivets per foot of bridge. The field rivets in the stringer cross-frames, floor beams, and stiff bottom laterals (omitting side stringers), for an ordinary floor, would be between three and four per foot; calling it three, we have 12 field rivets per foot of bridge, as the increase caused by the solid floor. The 48-ft. plate girder has 16 field

rivets per foot of span; the increased number due to the floor being about 12 as before. The field rivets per foot of span in some lattice girders are as follows:

One	$186\frac{3}{4}$-ft.	span	has 60.		One	110-ft.	span	has 35.
"	$155\frac{1}{4}$-ft.	"	" 55.		"	90-ft.	"	" 34.
"	141-ft.	"	" 42	(about).	"	70-ft.	"	" 30.
"	125-ft.	"	" 34.					

All of the above are single track through spans, and the field rivets are $\frac{3}{4}$ of an inch in diameter.

Fifth.—Aside from the box floor (see discussion of Floor), there will be but little exposed surface which cannot be painted after erection, no more, in fact, than in any ordinary bridge, whatever the form of truss.

Sixth.—With the exception of the floor, all parts of the work can be easily examined to see how structures are wearing.

Seventh.—The eccentric loading of the posts, due to the attachment of the stringers, while as fully provided for as in the best work, may be said to fall short of our ideal. There are enough diaphragm plates to carry the proper proportion of the loading from the inner to the outer channels of the posts, and the pin plates are sufficient for the pin bearing required, without counting the large $\frac{1}{2}$-in. plate on the track side of the post. It might be well to have the pin hole in this plate elongated somewhat to prevent its carrying any load directly to the pin. Plate hangers could be used for supporting the stringers; this would entirely do away with any possible trouble from the eccentric loading, but it would make the floor a little more irregular.

Eighth.—In case of accident, the truss members can be repaired or renewed as easily as in any ordinary structure.

Ninth.—There are no features which are more objectionable, from an artistic point of view, than our best truss spans show.

The Floor.—Solid or box floors of various kinds have been used for many years in Great Britain and on the European Continent. Some of the heaviest and most expensive structures built of late years have solid floors and ballast. Judging from its general use in Europe, we may assume that there are good reasons for adopting the solid floor in some form, in spite of the question of the cost, the uncertain distribution of the load, and the danger from rust.

In the *Transactions of the Society of Engineers* (London, Eng.) for 1887, there is a long and very interesting paper on "Bridge Floors, Their Design, Strength and Cost," by Mr. Edmund Olander. Abstracts from this paper were published in the *Engineering News* and *Railroad Gazette* during 1888. In this paper 10 styles of solid floor are taken for discussion and numbered in the order of their moments of resistance. Nine of these floor sections are shown on page 491, which were roughly sketched from the drawings given in the above paper. The tenth section was a pair of "Barlow rails" and was not used in the comparison. "These sections are reduced to one common weight per square foot of actual area covered, or as nearly so as practicable; they are also of the same depth, except No. 8, *i. e.*, 7 ins., and are symmetrically formed above and below the neutral axis." No. 1 is an ideal section, and was introduced by Mr. Olander for comparison only. No. 2 is patented, but little used. No. 3 is Lindsey's patent floor and is made from 4 to 12 ins. deep. No. 8 is Baillie's patent floor. Floor sections rolled in this country by two firms are similar to the No. 3 above.

In America the floor used for deck spans and where the clear width of the bridge is not too great, is the section No. 3 (known here as the Pencoyd "B" section). For the very heavy rolling loads now used, the above section is too shallow when spans are over 10 ft. wide, and the section No. 9 is generally adopted. Mr. Olander ranks this section No. 9 as the lowest in his list, it having the largest number of rivets and the lowest moment of resistance.

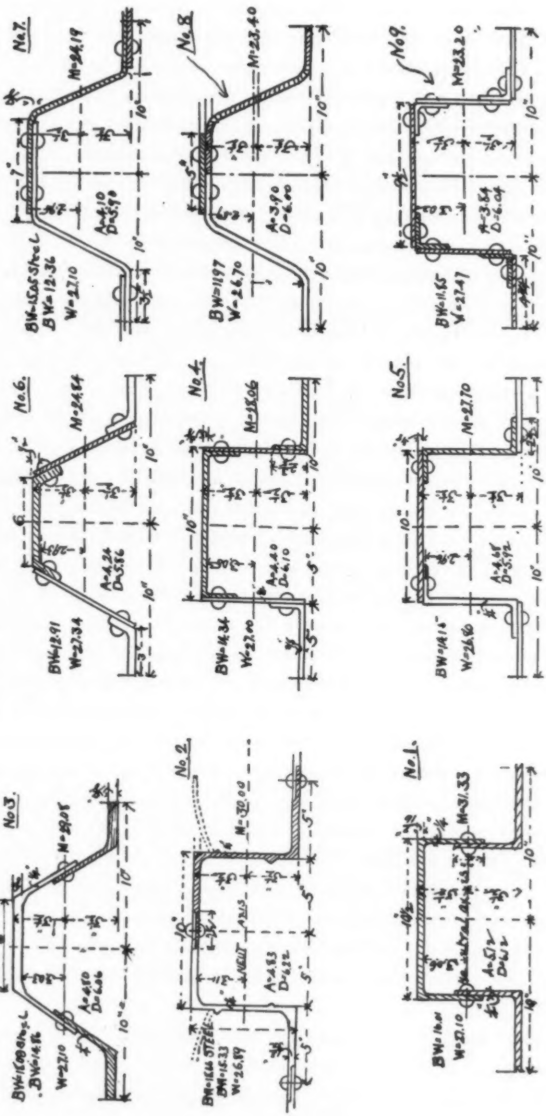
The writer's reasons for adopting section No. 9 are as follows:

First.—For through bridges the box floor must be suspended (on account of scant head room), which makes vertical webs necessary.

Second.—A floor is required in which the width and depth of the boxes can be easily varied.

Third.—In section No. 4 there are channel bars, the price of which is usually controlled by a pool. In section No. 5 there are Z-bars which are not, at present, rolled as deep as is necessary for our floor. At the present price of material there is a probable difference of $\frac{4}{10}$ of a cent per pound between an 11-in. rolled Z-bar and the material for a Z-bar to be built up; this difference should more than pay for riveting the built Z and the loss of area from rivet holes. The other sections are patented, and therefore not so desirable.

OLANDER'S SECTIONS AS DISCUSSED.



Distribution of Load.—Undoubtedly in a solid floor the most important question to be settled is the distribution of the heavy wheel loads. Comparatively few experiments have been made to determine the power of a box floor to distribute wheel loads. The manufacturers of the Baillie and Lindsey floors have made a good many experiments upon their sections, but for the square boxes there have been but few. The writer believes there have been several serious derailments and collisions upon bridges in this country, having solid floors similar to the one being discussed, but he has no record of them. Perhaps this record may be obtained in the further discussion of this paper. When the "Clyde Viaduct" was finished, somewhat crude experiments were made to determine, if possible, from the deflections, what could be assumed as the length of distribution. A 60-ft. plate girder span over a street and some 15 ft. above its level, was taken for the tests. The main girders were 15 ft. 2 ins. between centers; the floor was 12 ins. deep over covers and $11\frac{1}{4}$ ins. wide between centers of web plates. The flanges had 3 x 3 x $\frac{3}{8}$-in. angles and $\frac{3}{8}$-in. cover and web plates. A ten-wheel engine, having about 93 000 lbs. on three driver axles, was used for the tests, and the deflections were taken on the webs of the 16 boxes nearest mid-span. Fine wires were attached to the webs of the boxes, exactly under the middle of the track, and extended down into a long box of colored liquid in which they swung clear. The wires had iron weights and small smooth strips of pine fastened at their lower ends, so placed that the stains left on them indicated the deflections of the boxes. Wires were also fastened to the main girders and their deflections taken. In order to protect the wires from the strong wind blowing, a heavy piece of canvas reaching from the ground to the girders was drawn across two stakes and fastened at the top and bottom. The track was laid with even joints (66-lb. rails), one of these being almost exactly over the middle of the span. The deflections as recorded necessarily include the total for the girders and flooring, and can only be used to show the relative distribution of the load. In this span the base of rail was 1 in. above the top of the boxes, while in the plans submitted with this paper it is only $\frac{1}{4}$ of an inch.

Experiment No. 1. The splice bars were taken from the rail joints at the middle of the span, and the engine was stopped on the bridge, with the middle driver over them, the pilot being toward the left in

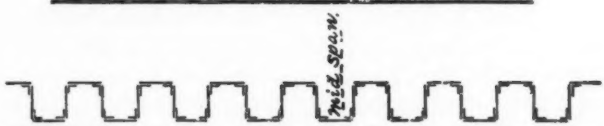
the sketch. After 10 minutes the engine was removed and the deflections recorded, except at *A*, *B* and *C*. Deflection of main girders was $\frac{9}{32}$ of an inch.

Experiment No. 2. Rail splices as before. The engine was run over the bridge at a speed of about 15 miles per hour. Deflection of main girder $\frac{5}{16}$ of an inch (full).

Experiment No. 3. Rail splices were replaced and the engine was run over the bridge at a speed of 20 miles per hour. Deflection of main girders $\frac{3}{8}$ of an inch (scant).

These experiments are shown in the following diagram.

Experiments 1-2&3. Clyde Viaduct.



	A	B	C	D	E	F	G	H	I	K	L	M	N	O	P	Q.
No. 1				9	10	10	10	11	11	11	11	11	11	10	10	9
No. 2	10	12	11	11	14	13	13	12	13	13	13	12	12	11	10	9
No. 3	12	12	11	12	14	12	12	11	13	12	12	11	12	10	10	9

ERRATA.

On page 493 of the November number, the following explanatory note should be placed below the figures:

NOTE.—The units in this table showing the deflections of the webs of the boxes, A, B, C, etc., represent thirty-seconds of an inch. Thus the deflection at D, in experiment No. 1, was $\frac{9}{32}$ in.

the moment of resistance of one box 26.28. Two sections ($3\frac{1}{4}$ lin. ft.),

* These two tests, and the description of the sheet of floor sections, are given as nearly as may be in the words of Mr. Olander in his paper.

riveted together, were placed on supports 14 ft. apart in the clear. A load of 14 016 lbs. suspended at the center gave a deflection of $\frac{5}{32}$ of an inch. This gives a working strain of 11 200 lbs. After this, further weights were roughly thrown onto the slings until the crippling weight of 68 200 lbs. was reached, when the deflection at centre was $3\frac{13}{16}$ ins.

Second.—No. 8. The section of trough tested was similar but somewhat heavier than that shown as No. 8, but was of the same form. It was $7\frac{15}{16}$ ins. deep, $\frac{7}{16}$ in. thick, and the flutes were 12 instead of 10 ins. as shown for regular section No. 8. This floor had an effective area of $5\frac{2}{10}$ sq. ins.; an effective depth of 6.85 ins.; a moment of resistance of 35.6 per flute and weighed $28\frac{1}{2}$ lbs. per square foot of area covered. A length of floor was laid with longitudinal sleepers and rails; the clear span was 15 ft., and the whole was supported by timber blocking roughly laid on the ground. Two pairs of car wheels were placed upon the track 7 ft. apart centers, and their axles loaded with bar iron. An assumed working load of some 77 300 lbs. was roughly deposited upon the axles of these wheels (4 ft. $8\frac{1}{2}$ ins. gauge), each of the four points receiving the same proportion of the load. When the above load was reached a deflection of $\frac{7}{32}$ of an inch was noted. (Mr. Olander thinks the actual deflection would not have been more than $\frac{1}{8}$ of an inch under the above load if the supports had been masonry or something unyielding. The timber blocking sank under the loading, or the pieces settled closer together, which increased the recorded deflection, as the gauge was not affected.)

When ballast is not used, the English practice has been to put 5 to 8-in. longitudinals across the top of the boxes, under the rails; by this method there are no cross-ties to give additional strength. The ordinary practice has been to assume that the length of the uniform distribution of any wheel load would be the distance between the axles of the wheels. In the paper previously referred to, the locomotive used has about 72 000 lbs. on two driver axles 7 ft. apart centers, and the load is, therefore, assumed as uniformly distributed over a length of 7 ft.

In this paper the typical engine assumed for the rolling load has 80 000 lbs. on two axles $4\frac{1}{2}$ ft. between centers, or 100 000 lbs. on two axles 7 ft. between centers. (Ten-wheel engines are now running on one Eastern road, in which the driving axle loads are over

38 000 lbs. each.) In accordance with ordinary practice, the writer would be justified in using 4½ ft. as the length over which one axle load of 40 000 lbs. is distributed, or 7 ft. for 50 000 lbs. Four boxes of flooring will cover a length of 4 ft. 2 ins., and the writer has taken this as the length over which the 40 000-lb. axle load is distributed. Under the above assumptions, the maximum bending moment for the total loading on four boxes is 1 362 200 inch-pounds; the moment of resistance for four boxes is 173, and "C" or the extreme fiber strain, is about 7 900 lbs., net. Counting the maximum loading as being distributed over but three boxes, the end reaction will be 9 200 lbs. per box, or sufficient for three ¾-in. iron rivets. The writer uses four steel shop rivets or five field rivets for the end of each box.

If stone ballast is used on the above floor, an extreme fiber strain of 10 000 lbs. will not be excessive for the medium steel used. While experiments to determine the exact distributing power of solid floors have not been numerous, the floors have given entire satisfaction where used. The writer has heard of no case in which they have failed on account of want of strength, even when theoretically overloaded. In view of all this, he feels warranted in making the above assumption as to distribution of load. In the floor under discussion the base of rail is but ¼ of an inch above the top of the boxes, and this will make the rail bearing almost continuous. Under service the cross-ties, by their beam action, will reduce the length of the moment arm, which in these plans has been taken as the distance from the rail to the end of the connection between the boxes and stringers.

In ordinary bridge designing it is customary to assume that the rails will distribute the wheel loads over at least three ties. The ties in the solid floor are spaced about the same distance apart as an ordinary roadway and have a 10-in. bearing face instead of 7-in., as in ordinary road ties. The writer has carried the ties on bent plates riveted to the upper flanges of the boxes, thus leaving a clear air space of several inches below them. If desired, a concrete, made of crushed coke mixed with asphaltic cement, can be used for filling the troughs sufficiently to carry the ties. This concrete will weigh, when dry, about 65 lbs. per cubic foot.* When the ties are supported in this manner, felt paper may be placed next to the metal under the concrete. Under service, the

* A filling somewhat like the floor arches used in fire-proof buildings might also be used. The increased weight per linear foot of track for this should not be over about 200 pounds, or a little less than with the concrete above noted.

metal work below the ties may be protected from moisture by pouring hot coal tar into the cracks between the concrete and metal. Experience will soon show how often this should be applied, but it would be a small item in the maintenance charges, if used quite frequently.

In case of derailment we have a clear, even floor for the wheels to roll upon, the ties cannot possibly be forced out of place, and the upper cover plates, presenting only about 6 ins. in width, unsupported by the flange angles, can hardly fail. Of course inside guard rails are to be used, though not shown on the plans, and also re-railing guards at the ends of the bridge.

Life of Floor, Weight and Cost.—The shop rivets in the floor (excepting sub-pedestals) can be machine driven, and by using proper care in painting the parts coming together the floor can be made water-tight. There is almost always a current of air across the bridge, through the floor boxes under the ties, and this will soon dry out the soil, coal, or other fine material that may find its way to the bottom of the boxes. The floor will drain itself completely, and the current of air beneath the ties will protect them from decay besides drying up any moisture that may gather in tie seats. Before the floor is riveted up at the shops, the parts coming together should be painted two coats, the first one being dry when the parts are bolted up. The entire floor should have two good coats of some liquid asphaltic paint before shipment and two after receipt at the bridge site; one of these being after erection. This should make the floor a lasting one. It can be painted during operation by loosening the guard rails and raising the ties onto the boxes while the troughs are being painted.

So far as their practical strength goes, the ties might be cut at the middle and held together by iron spike clamps driven into the upper faces. When the ties are used in half lengths they can be renewed without removing rails, by blocking the old ties up on to the boxes. When full length ties are used, the rails must be taken up for renewing the ties. It is expected that all the ties will be run through a surfacer and be brought to the exact thickness called for, so that no sizing will be needed. The end cuts for housing guard timbers can also be made at the mill. The surfacing and tenoning of ties can usually be more cheaply done at a mill than by hand in the field, and always much better done. Little if any fitting of ties should be needed at the bridge site.

The floor is made up of two sizes of plates and one of angles; these can always be quickly obtained at low rates. The manufacture is not troublesome, if fully understood, and it should not be expensive. A member of one of our large bridge companies informed the writer he thought this floor could at present be furnished f. o. b. at the shops, for about 2¾ cents per pound.

The weight of the floor will vary with the width and depth of the boxes, and the probable economical limits will be from 820 to 850 lbs. per linear foot of track. In the plans under discussion, the floor for the plate girders will weigh about 830 lbs. per foot (estimated weight of the floor is 41 700 lbs.), and the floor of the truss span will weigh about 835 lbs. per foot of track, omitting the extra weight of sub-pedestals. For the truss span a deep floor with four lines of stringers and angle laterals would weigh about 680 lbs. per foot, counting end beams and stringer cross frames.

Probable Cost of Bridge.—Will the increase in weight over the same class structure with an ordinary deep floor be sufficient to rule out our structure on the score of high first cost? Let us see. A very thin floor made of beams and stringers will probably weigh somewhat more than the same floor when sufficient depth is allowed. Side stringers will also be more necessary than with the ordinary deep floor.

		Lbs.
1st. A 150-ft. through pin-connected span with deep floor will weigh, approximately*........		228 000
Add excess due to stiff laterals.......	1 400 lbs.	
Add excess due to post brackets......	1 700 "	
Add horizontal bracing in trusses.....	16 500 "	
Add for side stringers................	37 300 "	
Add excess due to four panels stiff bottom chord......................	3 000 "	
		59 900
Total weight of completed span............		287 900
The 150-ft. span shown in plans will weigh.		346 300
Difference		58 400

This difference between the two spans, which is due to the floor, is 456 lbs. per linear foot of span.

* The writer is indebted to Mr. A. W. Stedman, Chief Engineer Lehigh Valley Railroad, and the Elmira Bridge Company for actual shipping weights of bridges built under Cooper's latest specifications, and for Lehigh Valley Company's rolling load.

	Lbs.
2d. One span S. T. deck plate girders, 50 ft. long over all, will weigh..........................	33 400
Add floor for through span (345 lbs. per foot)...	17 250
Approximate weight of one 50-ft. through girder span	50 650
If side stringers are used add 100 lbs. per foot....	5 000
One through plate girder, 50 ft. over all, total estimated weight of..........................	55 650
The girder span shown in plans (50 ft. over all) will weigh approximately..................	64 800
Difference.................................	9 150

The difference between the two spans is 183 lbs. per foot of track when side stringers are used and 283 lbs. when they are omitted.

The especial circumstances controlling each case must determine whether it will be best to use a permanent floor similar to the one here presented, or the excuses usually seen when such shallow floors are demanded. The writer believes that the low rate "per pound" at which this floor can be furnished will result in reducing the "pound prices" on a complete bridge below what they would be for the same structure with the floor made in the ordinary manner. Especially will it be the case when erectors have become familiar with this class of work.

It should be remembered that the writer is not advising the use of this particular floor for any places except where the head room is limited. Where there is sufficient distance, from the base of rail to clearance line, to allow the use of a deep floor, it may be best to use lighter trough sections (similar to No. 3), in case solid floors are desired.

In closing, the writer wishes to call attention to the common faulty manner of arranging the ties over the parapet walls at the ends of bridges. Usually these walls are finished to within 6 or 8 ins. of the base of rail and the ties laid directly upon the masonry. This is one of the most fruitful causes of accidents on bridges and nearly always makes a rough riding spot for passing trains. These ties on the parapet walls should be equalizers between the ordinary road bed and the bridge. There should be no appreciable swing or lurch to a train passing to or from a bridge. The writer's practice has been to use broad thin ties for these places and to fasten them upon 2-inch

blocks which rest upon the parapet walls and are about 7½ ft. apart in the clear. By this means the masonry lasts much better and the track rides more smoothly.

The following table, made up from one given by Mr. Olander, gives quantities and prices for the floor of an 84-ft. through plate girder span as built in England three or four years ago, and shows items that may be of interest:

TABLE.

Description of Floors.	Width of span c. to c.	Weight of flooring and ballast.		Per foot run of bridge.			
		Per foot run.	Per square foot.	Pounds floor plates.	Cubic feet timbers.	Cubic yards concrete.	Cost.
	Feet.	Lbs.	Lbs.				
Timber baulks 8 inches deep and cross-tie girders 12 feet apart................	16	992	62.13	....	10.70	....	10.63
	15	934	62.35	....	10.00	....	10.63
	14	876	62 57	....	9.3	....	9.39
	13	815	62.78	....	8.7	....	8.81
Timber baulks 10 inches deep and cross-tie girders 10 inches deep and 12 feet apart......................	16	1 111	69.46	....	13.3	....	12.95
	15	1 044	69.65	....	12.5	....	12.22
	14	977	69.86	....	11.7	....	11.49
	13	912	70.14	....	10.9	....	10.71
Barlow rails, concrete and ballast....................	16	1 868	116.66	512	....	0.16	11.97
	15	1 749	116.74	480	....	.15	11.24
	14	1 635	116.91	448	....	.14	10.46
	13	1 521	117.10	416	....	.13	9.73
Cross-girders 4 feet apart, 4 feet planking and cross sleepers..................	16	1 080	67.50	....	5.3	....	13.89
	15	1 012	67.55	....	5.0	....	13.14
	14	945	67.60	....	4.7	....	11.83
	13	878	67.65	....	4.3	....	10.71
Cross-girders 4 feet apart, arched iron plates $\frac{5}{16}$-inch thick and longitudinal sleepers..................	16	1 275	79.75	232	....	0.07	16.01
	15	1 196	79.80	220	....	.06	15.19
	14	1 118	79.85	207	....	.05	13.77
	13	1 037	79.90	207	....	.05	12.56
Cross-girders 7 feet apart, rail bearers, 4-inch planking and longitudinal sleepers..................	16	995	62.23	....	5.3	....	11.78
	15	941	62.87	....	5.6	....	11.24
	14	880	62.94	....	4.7	....	10.46
	13	818	62.99	....	4.	....	9.72
Cross girders 7 feet apart, rail bearers, flat iron plates, asphalt cinders and chippings.....	16	3 154	210.35	320	....	....	25 60
	15	2 950	210.86	300	....	....	24 19
	14	2 744	211.25	280	....	....	12.78
	13	2 536	211.30	260	....	....	21.41
Cross girders 14 feet apart, rail bearers, 4-inch planking and longitudinal sleepers..................	16	992	60.6	....	5.3	....	11.05
	15	912	60.87	....	5.0	....	10.42
	14	862	61.58	....	4.7	....	9.93
	13	813	62.62	....	4.3	....	9.93
Corrugated flooring 4 inches deep, over two main girders, 10 feet apart.....	16	459	30.98	290	....	....	8.37
	15	426	31.77	270	....	....	8.32
	14	408	32.72	250	....	....	7.79
	13	388	33.84	230	....	....	7.30
Trough flooring 7 inches deep, main girders 16 feet apart, type of section No. 3......................	16	536	34.80	434	....	....	11.15
	15	529	35.30	407	....	....	10.46
	14	502	35.91	380	....	....	9.83
	13	475	36.57	349	....	....	9.15

DISCUSSION.*

GEO. S. MORISON, M. Am. Soc. C. E.—I have twice used this class of floor, and in both cases I used it for reasons quite different from any which have been given this evening.

I used it on a bridge in the City of Omaha, between the Missouri River Bridge and the passenger station. This bridge originally carried seven tracks. I think it now carries thirteen. Its location is such that it was desirable to be able to lay tracks upon it in any position, and it was necessary to have a tight floor over the street. There was abundant height; and the bridge as built consists of plate girders, placed 6 ft. between centers on which is laid a corrugated iron floor made of the trough-shaped sections now rolled by the Pencoyd Iron Works after patterns prepared by me for this particular bridge. The troughs were filled with concrete and the floor was covered with ballast. I doubt whether the yardmen now know that any such bridge exists.

The other case was the bridge across the Willamette River at Portland, Ore. The question here was a very different one. The bridge had to cross a river on which navigation is excessive, so much so that the draw in this bridge has on more than one occasion been opened a hundred times in twenty-four hours. The river here was a little more than 600 ft. wide between wharf lines. Three hundred feet west of the west wharf line was a street, the established grade of which was the same as high water, and immediately west of the street were the depot grounds which our tracks had to reach. The street must be crossed either at grade or at least 12 ft. above it. If the latter alternative was chosen the entire depot grounds would have to be raised to this level. If the street was crossed at grade the height at which the rail could be placed on the bridge was limited by the ascent that could be made in 300 ft. I determined to cross the street at grade and to put the superstructure of the bridge as close to high water as I dared.

The bridge as built consists of a single fixed span 300 ft. long and a draw 340 ft. long, these two spanning the whole width of the river. The trusses are divided throughout into panels of 20 ft. each, and the bridge is a double-deck bridge carrying a railroad floor on the lower chord and a highway floor in the middle. The bottom chord was made stiff throughout. The floor consists of trough-shaped sections of basic steel rolled in England and is fastened only to the inside webs of the chord. The inside and outside webs are, however, connected by diaphragms at short intervals, so that the outside webs do their duty in carrying the weight. The sections as rolled did not correspond exactly to any divisor of the length of panel, and fillers were put in the riveted joints between the troughs so as to correct this dis-

* Mr. Robinson's closing discussion will be printed in the December number.

tance. In each trough was placed a tie, reaching the whole length of the trough, and deep enough to place the bottom of the rail about half an inch above the tops of the intermediate corrugations. The side plates of the chord are 24 ins. deep, and the bottom of the rail is about 18 ins. above the lowest point in the rivet heads of the chord. This made a very heavy floor and heavy chords. Both the fixed span and the draw are very heavy structures.

At the time this bridge was built I could find no evidence of any extreme flood in the Willamette River which was not due to back water from the Columbia River, and consequently was not accompanied by a current. The highest Willamette flood of which I had any record would have given nearly 10 ft. clearance beneath the floor. I considered, however, the danger of boats striking the bridge in this position so great that unusual precautions should be taken to prevent injury, and the adoption of the corrugated floor was not merely for the purpose of getting the track as low as possible, but for making the whole bottom of the bridge a horizontal plate girder which could stand blows at any place.

Within a year of the completion of this bridge, a flood occurred in the Willamette River, which was due entirely to the discharge of that river, and in the upper portion of the City of Portland was the highest flood that had ever been known. As the fall of the river was rapid and the bridge is in the lower part of the city, this flood at the bridge line did not reach the level of the highest previous back-water flood, but was only about a foot lower. The draw was kept closed during the flood, the turn-table was submerged, the pile fender-work above the pivot pile was washed away. The current was at least 8 miles an hour. The water was so near the chords that, where the piers obstructed the current, it dashed over the floor. There was a great deal of drift, much of it very large trees, the roots and branches of which were sheared off by this bridge; so many trees struck the chord that when I next visited it I could see along nearly the whole length slivers and splinters under every rivet head. The fixed span was fastened at both ends, the river end resting on an iron cylinder pier supported by piles which at the height of the flood stood in about 100 ft. of water; the spring of this pier takes up the expansion of the metal. Any ordinary truss bridge would have been destroyed, but the strength of the horizontal plate girder which formed the floor of this bridge saved it and it was entirely unhurt. I have some doubt whether a bridge like the one proposed by Mr. Robinson, which is really a pin-connected truss with an independent corrugated floor attached, would have stood that flood as well as the one which we built.

T. C. Clarke, M. Am. Soc. C. E.—This is a very interesting paper and considers the subject from two points of view besides that of thickness, one that of floors made of material not requiring renewal, the

other that of floors in which the noise can be deadened. It would be an excellent thing if we could get a lighter material than ordinary ballast. The writer speaks of a concrete in which coke takes the place of stone in cement, but if ties were laid upon that, it would make doubtless too solid a bearing ; there would not be the elasticity we need. When the rails are put directly upon the iron, without the intervention of wood, there is always a disagreeable noise, a vibration; therefore, it seems to me the best plan is that of the New York Central—putting in a ballast and putting the tie in that. A ballast was used on the Chicago and Alton road made of burned clay, but the objection to it was that after awhile the particles of burned clay became ground together and a great deal of dust was formed.

On the elevated railway in Liverpool, which is just being finished, they are using a floor different from any of those the writer has illustrated, in which the rails are placed upon a wooden stringer, as Mr. Morison has pointed out.

G. Leverich, M. Am. Soc. C. E.—A cursory examination of this paper and the accompanying plates, particularly Nos. LXI and LXIII, leads to these queries:

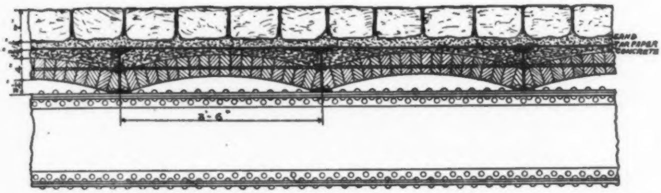
First.—Would not a large saving of material, as well as a greater certainty how the imposed stresses act in the lower members of the truss shown, result from combining the lower linked chord with the suspended riveted girder which supports the unique floor system; that is, by substituting for these two, a single stiffened lower chord, fully capable within itself of resisting the tensive and transverse stresses?

Second.—Will not this trough-like floor system rapidly corrode, particularly when on the upper side it is covered with ballast, or on the lower side it is exposed to the gases from locomotives or steam vessels passing underneath the structure, or in localities near the sea where the air is more or less saline? Again, can this corrosion be surely prevented by any paint or covering applied to the metallic surfaces; and may those charged with the care and maintenance of such structure be certain at what rate and to what extent this deterioration is going on?

The last query applies, more or less pertinently, to most designs for metallic bridge floors, including that for the Liverpool Overhead Railway, referred to by Mr. T. C. Clarke. Also, in this last, the material is necessarily placed unfavorably to resist transverse stresses. The thin plate, $\frac{5}{16}$ of an inch thick, is arched with 2 ft. 6 in. span and 15-in. rise; under a heavy rolling load, the arch will tend to flatten and the $4\frac{1}{2}$ x $3\frac{1}{2}$ x $\frac{7}{16}$-in. T, which forms the connecting lower chord, to move sidewise.

Attention is called to the flooring underneath the roadways of the New York and Brooklyn Bridge over Prospect Street, Brooklyn, and on a grade of 1.6%, a place where the headroom over the street was limited. It consists of a series of parallel longitudinal brick arches,

of 3 ft. 6 in. span and $3\frac{1}{4}$-in. rise, laid between 9-in. rolled iron beams. The arches are of a single course of brick 4 ins. thick, and backed with concrete $1\frac{3}{4}$ ins. thick at the crown; over this are granite paving blocks 7 ins. deep, upon a layer of clean, coarse sand, about $\frac{1}{2}$ in. thick—the total depth from spring of arches to the upper surface of the paving being about $16\frac{1}{2}$ ins.



Vehicles have passed over these roadways continuously since May 24th, 1883, often carrying the heaviest loads moved on city streets; and in one case, at least, 20 tons on four wheels, or from 6 to 7 tons on each of the two hind wheels. Since that time no repairs whatever have been necessary, and the underside of the arches now is as clean and free from cracks or leakage as when the masons removed the centers.

This construction was designed and superintended by George W. McNulty, M. Am. Soc. C. E.

J. P. Snow, M. Am. Soc. C. E.—Thin floors are oftentimes called for by the management of a railroad, by town committees, etc., when fair depth could be had by a little commonplace engineering. Except in towns and in the vicinity of important structures, I have very nearly always found it comparatively easy by studying the profile, to find a way to raise the track or lower the highway or stream so that a reasonable floor could be designed.

One frequent cause of unnecessarily thin floors is the wide difference that sometimes exists between the designer of the bridge and the track department of the railroad. The worst case of this sort that ever came under my observation was a railroad bridge over another railroad, designed by a bridge-building company under the direction of the General Manager of the railroad, who told the builders that the track could not be raised nor the clearance line underneath lowered. The bridge was built with the same depth of floor as the old structure, but meanwhile, before the masonry for the bridge was completed, the engineering department of the road was reorganized, and, to take a sag out of the track, the grade was raised 10 ins. There was no help for the shallow floor and the additional clearance was donated as a free gift to the lower road. The 10 ins. thus thrown away would have been a great boon to the designers and a great benefit to the bridge. We may note

this, in passing, as an argument for the employment of bridge designers as a part of the regular engineer corps of railroads.

The abolition of grade crossings in towns often demands, not only the thinnest practical floor, but a tight one as well. For these cases solid corrugated floors are undoubtedly the best solution, although

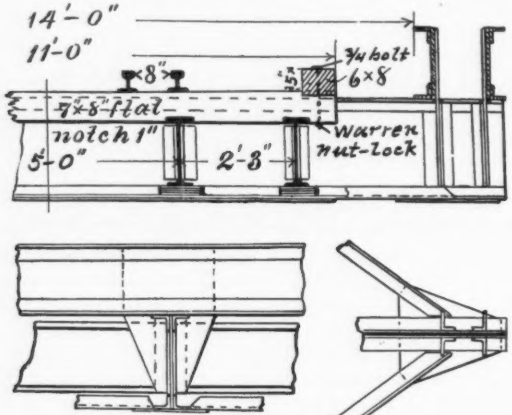


Fig. 1.

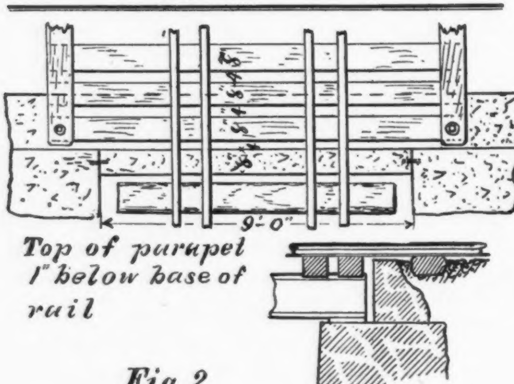


Fig 2

valid objections can be urged against them. Where the existing conditions of adjacent property will admit of a depth of, say 2 ft. between base of rail and clearance line, I prefer a floor of timber ties on metal stringers, and will confine my comments to this class.

In truss bridges the floor beams must, of course, be headed into the lower chord or suspended below it. I prefer the latter with plate

hangers riveted to the chord. This rules out eye-bar chords for cases of restricted floor depth, and, although I consider a well-proportioned eye-bar an ideal tension member, while a section made up of angle irons, plates, etc., punched full of rivet holes is not; still, where we must suspend the floor beams, I would use the built section for a bottom chord. The sketch, Fig. 1, shows a detail that I have frequently used with satisfactory results. The hanger plates are slotted and the horizontal flange of the top angles of the floor beam cut away. It is applicable to both pin and riveted trusses, with the proviso that the bottom chord be always riveted. It furnishes a rigid bracket for transferring the longitudinal component from the lateral bracing to the chord, and it gives ample room for hanger rivets in the four upright angles at end of floor beam. I have used it in many highway bridges over the tracks when the headroom was limited, and find no difficulty in cutting away the top floor beam angles in overhanging sidewalks of ordinary width. In bridges carrying more than one track we must put a truss in the space between tracks, and we must in all cases have short panels. All of these things add to the cost of the bridge and violate the prevailing fashion, but, if properly proportioned, do not detract from the efficiency of the structure.

The sketch shows a bridge 14 ft. in clear width, the same as mentioned by the author; for this width I would use ties 11 ft. long, shown in Fig. 1. Many of our bridges are wider than this and admit a 12-ft. tie. The principal office of the timber on the ends of the ties is that of a spacer, but in case of a derailment it should act as a guard as well. When called upon to act in this latter capacity, it must be far enough from the truss that the car body will clear it when the wheel is against the guard timber, and it must also be far enough out from the track to clear the snow plow. In the author's design it is difficult to see the use for the 12-in. timber on the ends of the ties, for the ties need no spacer, as they could not possibly bunch, and it lies so near the truss that the car body would be in solid collision while the wheels were several inches away from the timber, and it is hardly high enough to be effective against the truck frame and housings. I believe, however, that the inside rail is far more effective as a guard than the outside timber. They should be brought together about 35 ft. from the parapet and bolted to an old frog point.

I concur with Mr. Robinson in his criticism of the prevailing arrangements of parapets. How often do we see bridges with no apparent kinship to the masonry that they stand on? The bridge designed by its builder, and the abutments by the surveyor or stonemason employed by the railroad—the bridge builder knowing but little about the possibilities and limitations of stonework, and the other man but little how the bridge will look until he sees it delivered. I hold that the party who designs the bridge should also design the masonry, at least from the bridge seat up. This is another argument for the employment of bridge engineers by railroads.

I present a sketch of a parapet (Fig. 2) that I think much better than that described by the author. I first saw it used on the Providence and Worcester Railroad, now a part of the New York, New Haven and Hartford system. If the stone is low enough to admit even a thin tie on it, the ballast material will get over into the bridge seat and I should expect the 2-in. shims described to be very soon crushed out. The top stone should be in one piece 9 ft. long, but two short ones well doweled together will give no trouble. The shape shown is not expensive to get out in granite—a skillful mason will break them to shape with very little pointing. The ends of stringers should be only 2 or 3 ins. from the face of the stone, and, if the bridge has an end floor beam, it should have stringer brackets long enough to take one tie next the parapet. In skew bridges the parapet should always be squared ; if the bridge is double track, it is generally best to square each track separately, using a narrow header between, into which each parapet stone heads. There is no trouble in building a skew bridge seat in connection with a square stringer seat and parapet.

George H. Thomson, M. Am. Soc. C. E.—Mr. Robinson finds difficulty in connecting solid floors to lattice girders, principally on account of the panel points—where the web members occupy the space in chord required for floor attachment. This will hold for old-fashioned latticed bridges, but will not hold with modern lattice bridges, as the web members join the chords, at panel points, through the media of panel-point plates which leaves the bottom of bottom chord open and free for the requisite floor attachments (Fig. 1, page 508).

There is no difficulty in making a bottom chord section for lattice spans of a magnitude of, say, 500 ft., double track, though at the present date, economy will not warrant the open chord with solid floor for spans above ordinary magnitude. The writer designed (for Walter Katté, M. Am. Soc. C. E., Chief Engineer of the New York Central and Hudson River Railroad) some two years ago a swing bridge of over 400 ft. length, and supporting four tracks, and found no difficulty in the design of chords supporting the floor.

The new viaduct known as Park Avenue Improvement, City of New York, for the traffic of the New York and New Haven, Harlem River, New York Central and Hudson River Railroads, is to be a plate girder construction with solid floor, for four tracks, 1¼ miles long, as per the recommendation of Mr. Katté.

The four-track swing bridge over the Harlem River, New York (for the railroads above mentioned) a structure of 400 ft. length, is to have a solid floor, and the designs under consideration are of the pin-connected, lattice and composite type, *i. e.*, connections part pin and rivets.

The writer has designed and erected within five years past 300 spans of solid floor bridges of all types and kinds, many of which

are upon the lines of the New York Central and Hudson River Railroad Company, reviewed, selected and adopted by its Chief Engineer.

In practice, the plate girder is used ten times to one use of the lattice bridge for solid floor work.

Fig. 2 (page 509) shows detail of a bridge about 400 ft. long. The rails are laid with the ordinary cross-ties with 6 ins. of broken stone ballast between the tops of troughs and bottom of ties. The bottoms of troughs are filled with asphalt concrete laid to drain to the center. Some difficulty is experienced in making the troughs fit the girders, owing to the stretch of the former after manufacture.

Fig. 3 (page 510) shows detail of one bridge about 400 ft. long and a number of other bridges spans of 50 to 100 ft. The section is cheaper than section shown on Fig. 2.

Fig. 4 (page 510) shows floor sections and attachments to a plate girder bridge of 98-ft. span, similar to a number of other two and four-track bridges of less span. In a use of this floor for four years with cross-ties ballasted, as shown, there has been no difficulty in keeping the cross-ties ballasted to surface and grade.

Fig. 5 (page 511) shows the method of connecting floor to web of main girders extended below the bottom flange with a minimum floor thickness of 13ins. This plan is not applicable to long girder spans.

Fig. 6 (page 512) shows a span (three-track) of 24 ft., with corrugated floor. Small spans can be made much cheaper as per plan shown on Fig. 7 (page 513), a type known as the "longitudinal trough," of which there are many examples on the New York Central and Hudson River Railroad. Its limit of span at present prices is about 34 ft.

The longest single track lattice span erected by the writer is 200 ft., center to center of end bearings.

Rail floors consisting of rails laid longitudinally for spans of 8 x 10 ft., when covered with broken stone ballast, make a very satisfactory structure. Rail floors are sometimes laid cross-wise on top of deck plate bridges. Fig. 8 (page 514) shows one such floor in use, on the Harlem Railroad, where the foundations of abutments were of a character requiring the cushioned track, as shown.

The growing demand for accelerated speed for passenger service, with the consequents obtaining from the antecedent of the high speed itself, will probably suggest advance in the design of structures. The solid floor bridge meets the new and coming conditions, so far as can be seen, when ballasted, and especially (from an observation extending over four years on a number of bridges of solid floor ballasted type in use for heavy traffic) for bridges of minor spans.

A considerable number of abutments and piers hammered out by deck plate bridges of small span, coming within the experience of the writer, will require an outlay to rebuild them equal to ten times the cost of new solid floor bridges ; the injured masonry, however, will sustain the solid floor bridges, though not equal to the task of sustaining the old-fashioned plate bridges.

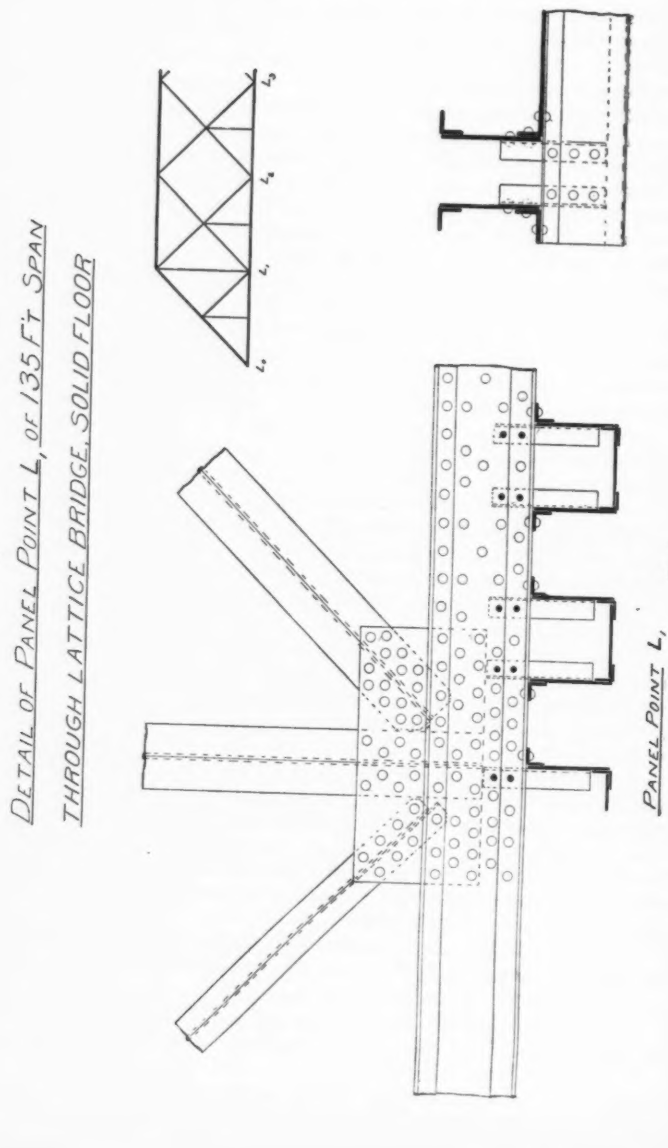

DETAIL OF PANEL POINT L1 OF 135 FT SPAN
THROUGH LATTICE BRIDGE, SOLID FLOOR
L0
L1
L2
L3
PANEL POINT L1

FIG. 1.

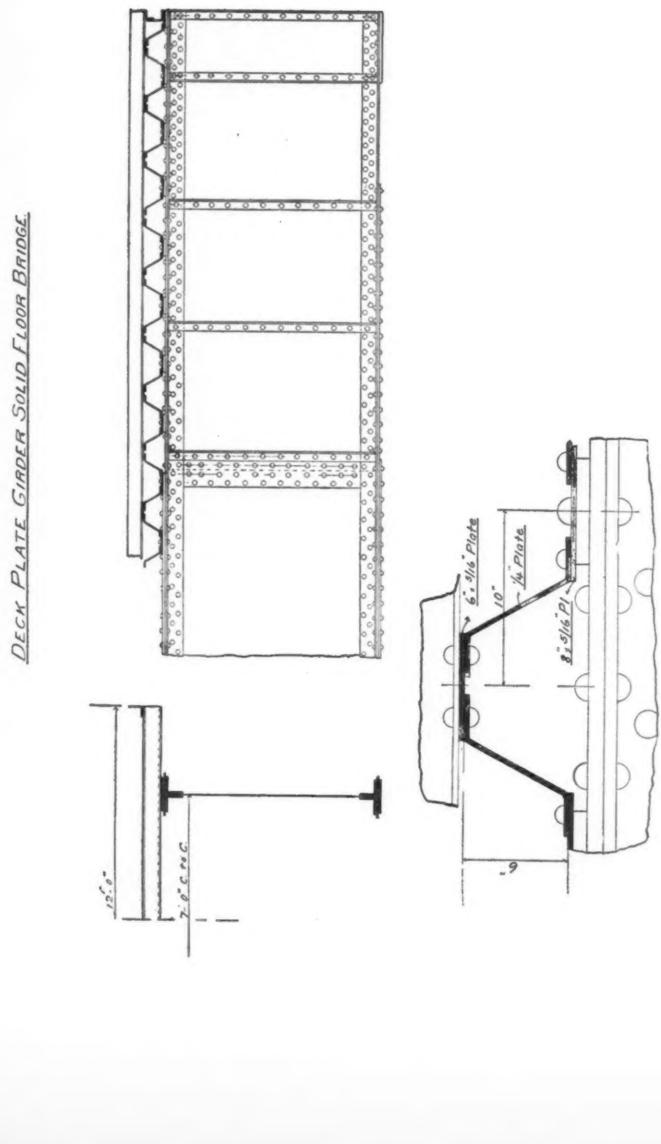

Deck Plate Girder Solid Floor Bridge.
12'0"
7'0" c. to c.
6" x 5/16" Plate
10"
1/4" Plate
8" x 5/16" Pl
6"

Fig. 2.

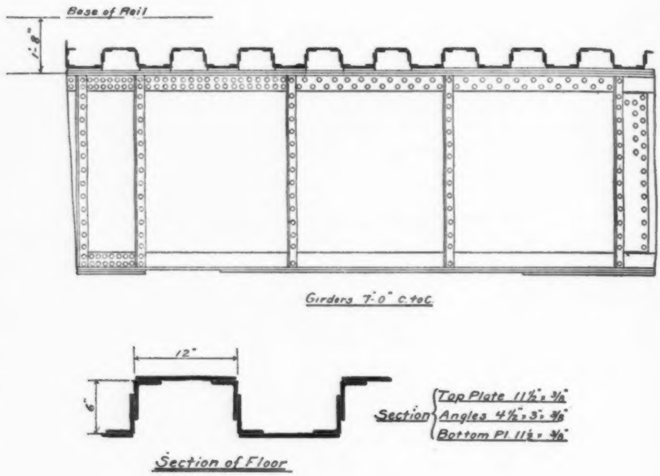

Base of Rail
1'-8"
Girders 7'-0" c. to c.
12"
6"
Section
Top Plate
Angles
Bottom Pl.
Section of Floor

FIG. 3.

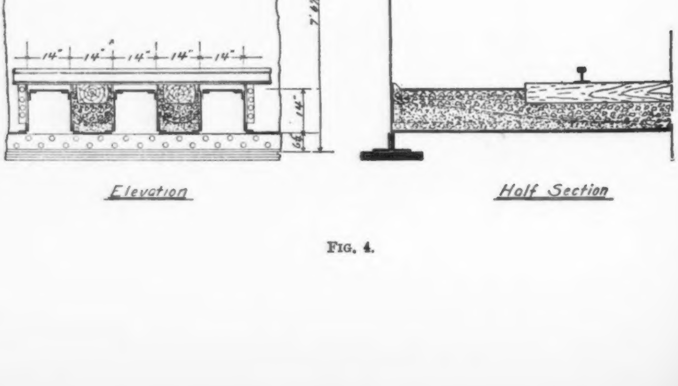

15'-1½" c. to c.
14"
14"
14"
14"
14"
7'-6½"
14"
Elevation
Half Section

FIG. 4.

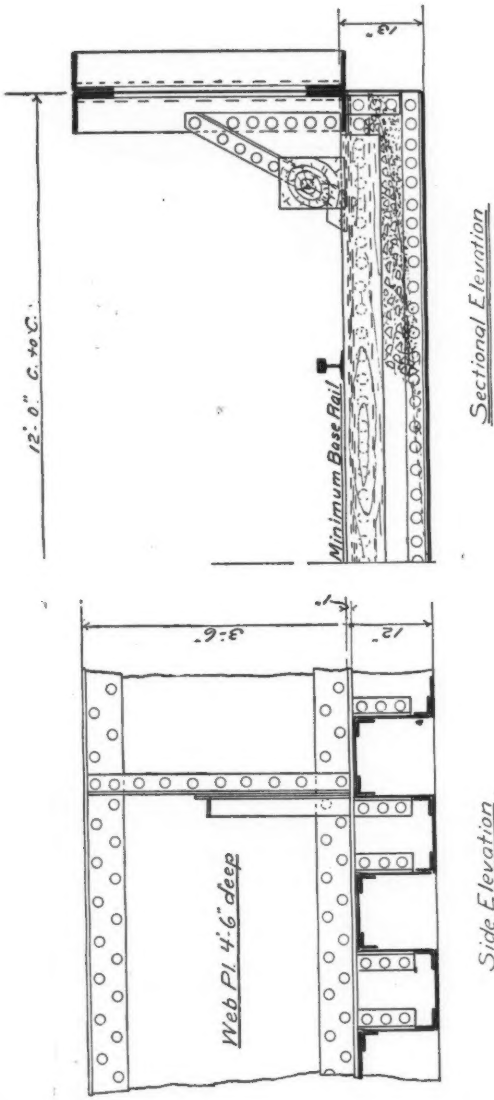

12' 0" C. to C.
13"
Minimum Base Rail
Sectional Elevation
3' 6"
1"
12"
Web Pl. 4' 6" deep
Side Elevation

FIG. 5.

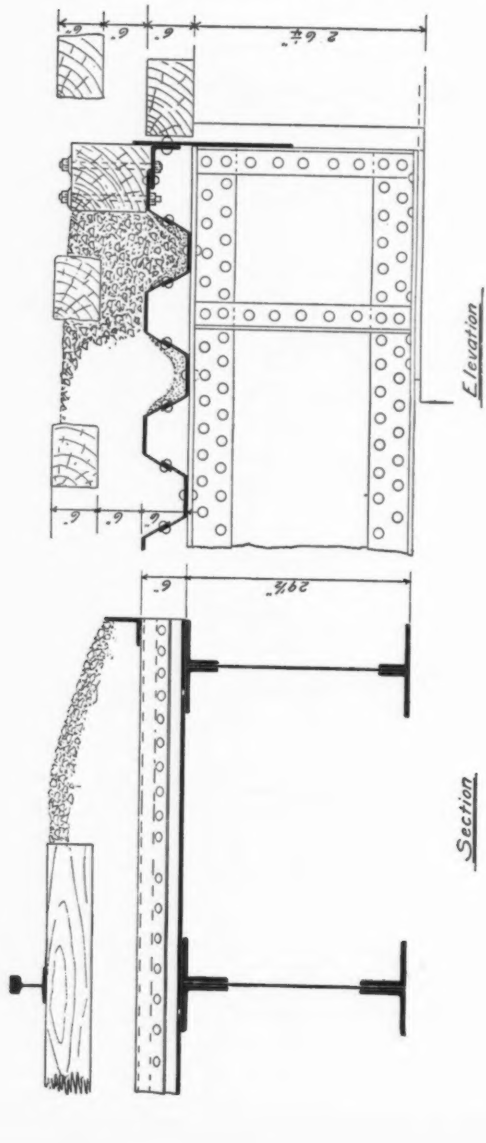


FIG. 6.

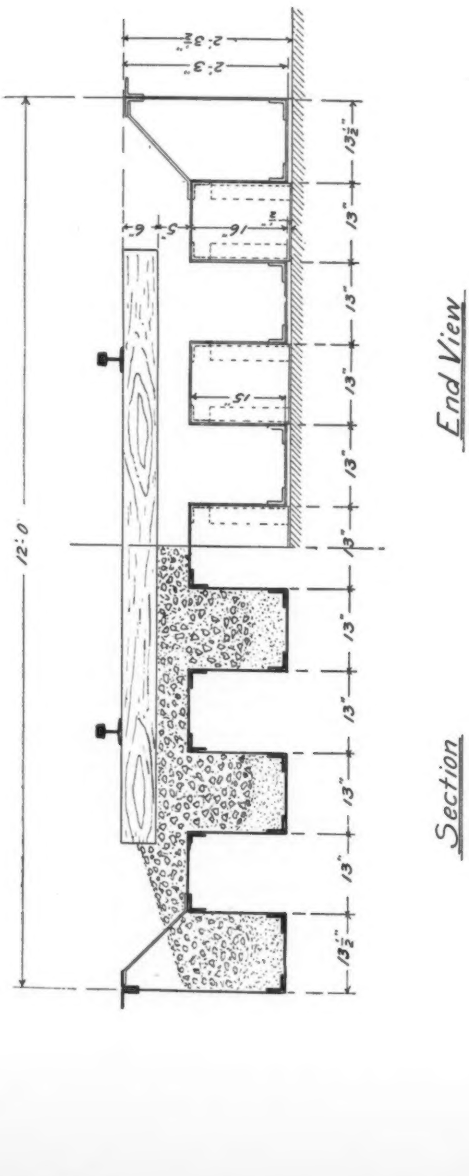


Fig. 7.

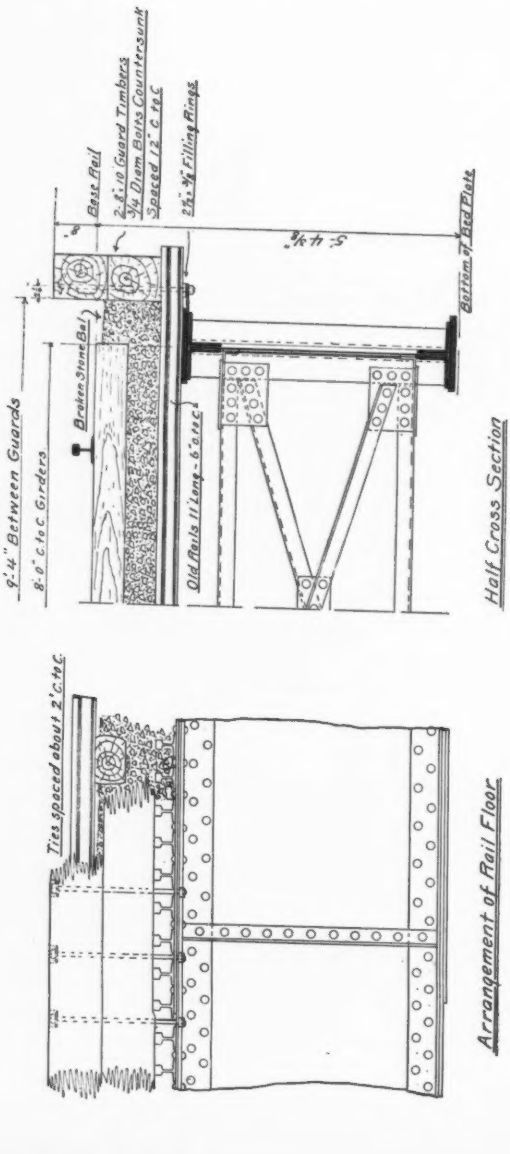

9'-4" Between Guards
8'-0" C. to C. Girders
Broken Stone Bal.
Base Rail
2-8"x10" Guard Timbers
3/4 Diam Bolts Countersunk
Spaced 12" C. to C.
Filling Rings
Old Rails 11' Long - 6" c. to c.
Bottom of Bed Plate
Half Cross Section
Ties spaced about 2' C. to C.
Arrangement of Rail Floor

FIG. 8.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

560.

(Vol. XXVII.—November, 1892.)

RAILWAY SIGNALING AS APPLIED TO LARGE INSTALLATIONS.*

By John P. O'Donnell, M. I. Mech. E.

Read October 19th, 1892.

Of the two papers on this subject, so far as the knowledge of the writer extends, that have been read before any prominent institution in Great Britain, the one read by Mr. Richard C. Rapier, M. I. C. E., on "The Fixed Signals of Railways," contained a brief history of the first signaling plant of any description ever erected in Great Britain (or, the author believes, upon any railway) and carried it through the various stages of improvement and development, to the then considered perfected state of signaling in 1874. Even at that early stage, recognition was given to the duties to be performed by, and the qualifications needed from, a railway signaling engineer. Mr. Rapier very aptly described the position of railway signaling when he said, that it is a trite axiom "that two solid bodies cannot occupy the same space at the

*Discussions received before January 15th, 1893, will be published in a subsequent number.

same time." The duty of a railway-signaling engineer may be said to be, to endeavor to prevent two bodies which are moving at high velocities from seeking to violate this law of Nature.

Previous to and including the year 1874, interlocking had not developed to any very great extent. That is to say, the most recent interlocking apparatus, and the most approved at that time, was the one invented and patented by Messrs. Stevens & Sons, of London and Glasgow. In this apparatus what we understand now by an interlocking tappet was first applied. Practically, there has been little or no improvement upon that locking form to the present time, except in the fact that, whereas in Stevens' original apparatus the locking was effected by the movement of the lever, at the present time the railway public seems to favor preliminary actuation of the interlocking by means of the catch handle.

The next paper, and the latest, so far as the writer is aware, was a paper read in the year 1884 by Mr. Arthur Moore Thompson, Signaling Superintendent of the London and North Western Railway, on the signaling of that railway. The subject-matter of this paper was a very careful and accurate description of the mechanical details of signaling, more particularly the various devices and appliances used throughout the London and North Western Railway. There was little or no attempt made to discuss any large installations or to establish any principles or standards in reference to the practice of railway signaling. A very excellent code of rules was given for the guidance of the men in the signaling department.

Since the year 1884, many developments and improvements in signaling have occurred. The writer has endeavored, during his short visit, to make himself conversant with the general practices and results aimed at by the traffic managers of this country. There is in this country no supreme authority corresponding to the English Board of Trade, which lays down rules for the guidance of the companies in the matter of the safety devices they should adopt. It is left rather to the good sense of the railway officials themselves and their interests, to provide for the safety of the public. It is obvious when this is the case, that each company's engineers view things in their own individual light. There are such divergent views in connection with the moving of signals, that the writer ventures to suggest that it is extremely necessary that some general principles and rules

should be laid down for the guidance of all railways in the matter both of railway signaling and appliances, and in the instructions to their signalmen and engineers as to the manipulation and meaning of the signals.

In looking over the paper read by President H. S. Haines before the meeting of the American Railway Association, October 12th, the writer notes that efforts are being made in the direction pointed out, to provide train rules and to endeavor to have a standard code made for the guidance of all railway officials, corresponding in some degree and possibly under changed conditions to the books of rules in use on every British railway.

In this connection it should be said that these remarks must necessarily, to some extent, be a comparison between the manners and rules adopted in England (with which the writer is familiar) and, so far as he can gather in the short visit just made to this country, the rules and general ideas prevalent in connection with signaling here.

In Mr. Haines' paper, there is a passage in which he says:

> "The idea of maintaining intervals of time between trains has been realized in various ways; as by track sentries, by the display of signals at curves or at other specially hazardous points, or by a record at stations, visible from passing trains, showing the time that the last train had passed in the same direction. The method of time intervals between following trains affords efficient protection so long as the trains maintain an uniform schedule speed, can be readily stopped within the recognized time interval, and are not liable to unexpected delays between signal stations. These conditions prevail on roads doing principally a passenger business with light and frequent trains, and such roads can be and are now successfully operated under this method."

The writer was led to believe that time intervals had been abolished in this country, and were not now in operation on any important road. Even from what Colonel Haines says, and we might all endorse the statement, a time interval does not afford efficient protection on roads that have a heavy traffic, unless those intervals be so extended as to seriously interfere with business. If this is so, it is obvious that it would not be adopted or even looked upon with any degree of favor by any line of importance in this country, as the freight traffic is sufficiently important to give consideration to any means which would enable rapid movements to be conducted.

With reference to the remark in Colonel Haines' paper that "the circumstances under which distant signals should be required will

affect the rules for operating a block system as well as the essential requisites for the proper appliances," it would seem to require qualification, as under every condition of the block system a distant signal is needed.

The following in Colonel Haines' paper appears also to require explanation, that "railroad managers, civil engineers and inventors are trying to remedy what is called the deficiency in the block system, and it is because the Train Rule Committee is conscious of these facts that it has hesitated to endorse the block system as now used." In England, on such lines as the London, Brighton and South Coast, the London, Chatham and Dover, the South Eastern, and other important railways, the union of the lock and block system is carried out, and, with that safeguard, under the absolute block system, it is almost impossible to have rear collisions. The leading idea in American signaling seems to be to eliminate the human agency, but it is submitted that the endeavor to force an automatic system at the present moment is untimely. The system will be found to be costly, confusing and unnecessary, as the concentration of points and interlocking them becomes, as it must, more generally adopted. The writer thinks it would be generally agreed that the normal condition of the signal should be the danger condition.

A point which seems to be not yet settled satisfactorily in this country is the question of arranging the signal arms to indicate high-speed routes and the various lines traveling either side by side or diverging, as at a junction. The writer had occasion yesterday, through the courtesy of the New York Central officials, to examine the pneumatic plant at Woodlawn Junction on the Harlem Division of the New York Central and Hudson River Railroad. The system appears to be to arrange the top arm always for the important road, irrespective of whether it was right or left. In England the rules are the very reverse, and would appear to be supported by simplicity and by ease of understanding. It would appear to be simpler to take the left-hand top arm for the left-hand road and the right-hand top arm for the right-hand road, especially when such arms are fixed on separate posts.

The writer also noticed in the same scheme that shunting signals were provided, shunting back on the south-bound track in the north-bound direction, and he gathers that such provision is usually made in

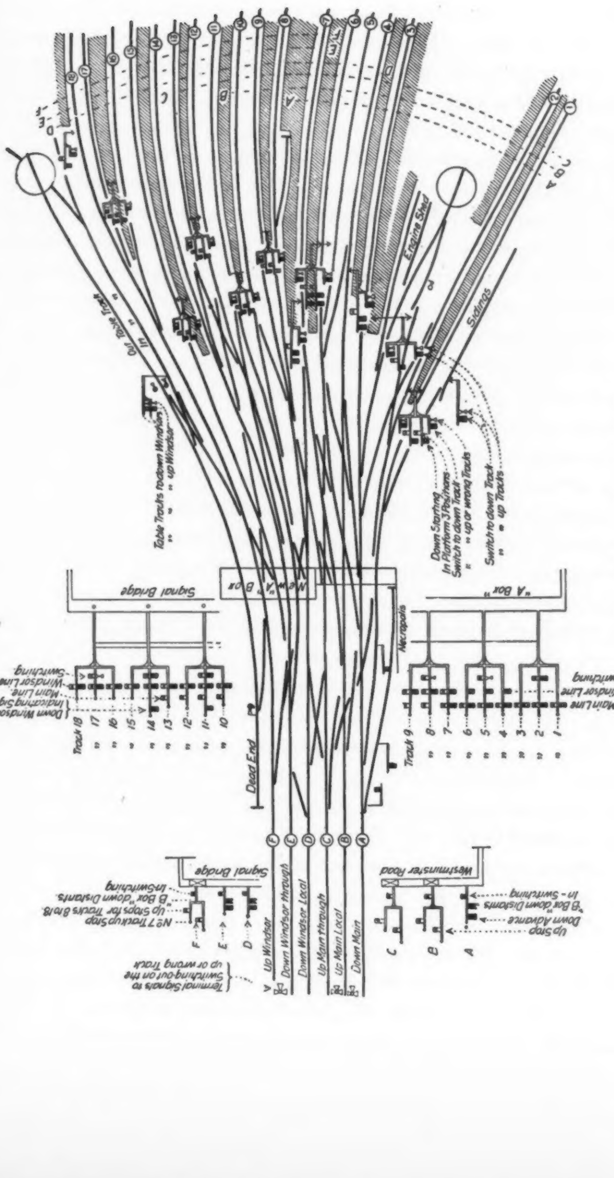
signaling schemes in this country for shunting onto a wrong road. It would appear to be a dangerous precedent to give an engineman absolute authority by signal to shunt in the direction of meeting an approaching train. Our custom in Great Britain is to perform such movements, when needed, by special authority, as we consider that when an engineman has received a definite outside signal to proceed, if he so proceeds, should any accident result through his obeying the signal, he is exempt from responsibility. In your system the risk of running back on the wrong road, the engineman supposing he is on the right and meeting a train from the next section, would appear to be great. We have had many such accidents in England, and the writer notes especially one which occurred in his own experience, at Kingston, on the London and South Western Railway, where an engineman thought that the crossing points had been moved for him to proceed to the right road; the points themselves had not been moved at all. He proceeded to the next section on the wrong road, met a train coming in the opposite direction, with the result that eight people were killed. No wrong road movements are allowed by signal at any place, to the writer's knowledge, except at Waterloo and one or two other large terminal stations; but at all intermediate through stations corresponding to Woodlawn Junction, no such provision would ever be sanctioned.

The subject-matter of this paper was originally intended to be a description of the appliances and methods adopted by the company, and the designer in the signaling at the Waterloo station of the London and South Western Railway. At this station, as far as possible, each distinctive movement is signaled; that is to say, a passenger movement, an in-shunt movement and an out-shunt movement. Everybody in the station, the engineman, the man on the ground, the inspectors on the platform, everybody concerned, is given an intimation as to what movement is to take place. If an engine is to be shunted in the station a distinctive signal is given, showing that it is an engine; if it is a passenger movement, a different and distinctive signal is given to that effect. In this country, the custom seems to prevail to signal the route, without reference to the composition of the movement; that is to say, the same signal is given into a station for a passenger train, as for an engine, or a shunting movement.

It is claimed that the new signal box and the signaling scheme or sys-

tem at Waterloo is, in general, the largest in the world; but, on the other hand, it has been said that the London, Brighton and South Coast Railway signal box at the London Bridge terminal, which contains 280 levers, and the London and North Western Railway signal box, at the Euston terminal station (London), which contains 283 levers, are larger than the Waterloo station system. It is true that the Waterloo signal box contains only 236 levers, 23 of which are gear and locking levers, and are simply put in for the assistance of the interlocking; but the Waterloo plant has been carefully and specially designed to be operated by as few levers as possible, and it is further claimed that if this plant had been arranged with the same liberality in the use of levers as that at any other of the large stations, between 400 and 500 levers would have been required.

Previous to the year 1878 there were 10 passenger tracks, being those from 3 to 12 in the general plan, Fig. 1 (page 521), which represents the arrangements as finally completed in May, 1892. In 1878 the two platforms 1 and 2 were added, and in 1885 five additional tracks were added at the north side of the station as well as all the side tracks for Windsor trains at the north side of the station. The platform and passenger track accommodation has been practically doubled since 1878. For some years past work has been in progress on the widening of the four-track masonry viaduct over which the railway runs to the Waterloo station, and this has recently been completed, giving six approach tracks. The telegraph wires along the viaduct became so numerous that they have been all placed in underground conduits as far as Clapham Junction, and it has, therefore, been possible to place the semaphore arms or blades much lower than would otherwise have been the case. The viaduct work and new tracks have been constructed under the supervision of Mr. E. Andrews, Chief Engineer, and Mr. A. W. Szlumper, Resident Engineer. On April 9th, the day of the Oxford and Cambridge boat race and the Sandown Park horse races, there were 819 incoming and outgoing trains, or an average of 45 per hour. To control this number of trains according to the ordinary method in use, involves 18 000 lever movements and the sending of 20 000 electric signals. During a few hours in the busy time in the morning the number of switching operations was 173, while from 4 P.M. to 6.40 P.M. the number was 131. In 1874 the number of levers in the old "A" signal box was 109, and



Plan of Track and Signal Arrangement.

FIG. 1.

the average number of movements was 10 per train, including switching, there being then no facing switch locks in use. With this additional safeguard provided, the average number of movements required is now 22 per train, and the number of levers in the old "A" signal box, previous to the new arrangement recently completed, had increased to 209, giving an aggregate of nearly 5 250 000 lever movements during the year.

In regard to the arrangement of the plant, it is said that at London Bridge, Euston, Cannon Street, or any other of the large London terminals which are provided with large signal boxes, every movement—that is to say every signal—is worked by a separate lever, and one signal is often worked by more than one lever. Special levers are provided in order that the locking may be reduced, and the writer is informed that, generally, levers are recklessly provided, so that special locking shall not be necessary in the interlocking apparatus. When the new Waterloo arrangement was originally devised, the writer concluded that where a series of tracks lead into one track, or where more than one movement takes place from one track to another, it would be a waste of levers and mechanism to provide separate levers for each movement, provided that not more than one of such movements should take place at once. Take, for instance, an inbound train on the "up Windsor" line in Fig. 1. A signal is provided to give authority to run to, say, platform track 14; a separate signal for switching from the "up Windsor" track to platform 14, and a third signal for switching out from the platform to the incoming track or "wrong road." It is evident that out of these three distinct movements only one at a time can be given with safety, and that it is no inconvenience to traffic to arrange one lever to work the three signals, each signal being given separately, as desired, according to whether it is a passenger movement, a switching-in or a switching-out movement. The explanation with reference to the "up Windsor" track, and platform 14, applies throughout the scheme, from the "up Windsor" track to all the platform tracks that can be entered from that track, which includes down to platform track 7. The same takes place from the "down Windsor" through track. There are out-passenger signals for that track, switching-out signals to it, and switching-in signals from it to any platform which can be entered from the same track and the roads to it. The same traffic facilities by signal are provided for the "down Windsor"

local, "up main through," "up main local" and "down main" tracks. The curved, dotted lines across the platform tracks on the right of Fig. 1 indicate the several tracks which can be entered from each of the six approach tracks.

To provide the usual full number of levers for the signals only in connection with the six main tracks approaching Waterloo and the signals out in connection therewith, it is said that it would have taken about 230 levers, and that at any of the other large stations such a number of levers would have been provided for the large number of signals which are necessitated at the station. At Waterloo, however, to work the signals named, there are provided only about 74 actuating levers and 6 gear levers. This has been effected by the adoption of the No. 4 "Simplex" machine for interlocking gear. This machine is already extensively used on several railways. By its adoption the railway company was enabled to save the difference between 80 levers and 230 levers, or about 150 levers saved in the locking frame. As already noted, it is said that if Waterloo had been signaled with the same complication that other of the large stations are signaled, there would be required in the "A" box between 400 and 500 levers, instead of 236 as now provided. Practically every switch in the yard is a facing switch, and provision is made for the use of all platforms as both arrival and departure platforms, while the interlocking has been so arranged, that where a train can get into a platform track by more than one way, such other ways are properly interlocked and provided for, and safety is given by signal and not by flag. Hand signaling has been practically abolished. The number of levers is as follows:

Signal levers, working 247 signal connections	102
Switch levers, working 81 switches	50
Facing switch lock levers working 68 switches	46
Gear levers working to three positions	7
Setting levers for alternative routes	16
Space levers	15
Total number of levers	236

The locking frame was supplied by Stevens & Sons, of Southwark, and the work has been carried out by the London and South Western Railway Company.

As will be seen by the plan, the new "A" box spans only a portion of the lines entering the station. Owing to the exigencies of the situation, the line approaches the terminus with reversed curves, and the northern portion of the station is laid out on a curve. The situation chosen for the new box nearly covers the site of the old structure, and is chosen as giving the best views into the various platforms and down the line.

It has hitherto been the custom to erect lofty semaphores for signaling purposes, with long rows of signal arms relating to the various lines. The difficulty to an engineman in distinguishing his proper signal must be great under such circumstances, and it has been sought in the "A" box to range the arms over their respective lines. One of the station signals comprises 67 arms and another 21, while there are 12 bracket signals at the ends of the platform. Occasionally a train or engine has to switch onto the wrong road, and this exceptional movement is signaled by means of a "scissors arm" by day, and a purple light—instead of a green one—at night. A short distance along the line, where such movements would be a danger to the traffic, an automatic signal is constructed which places three detonators or torpedoes in succession on the line, the explosion of which would give a report sufficient to recall the engineman to a sense of his position.

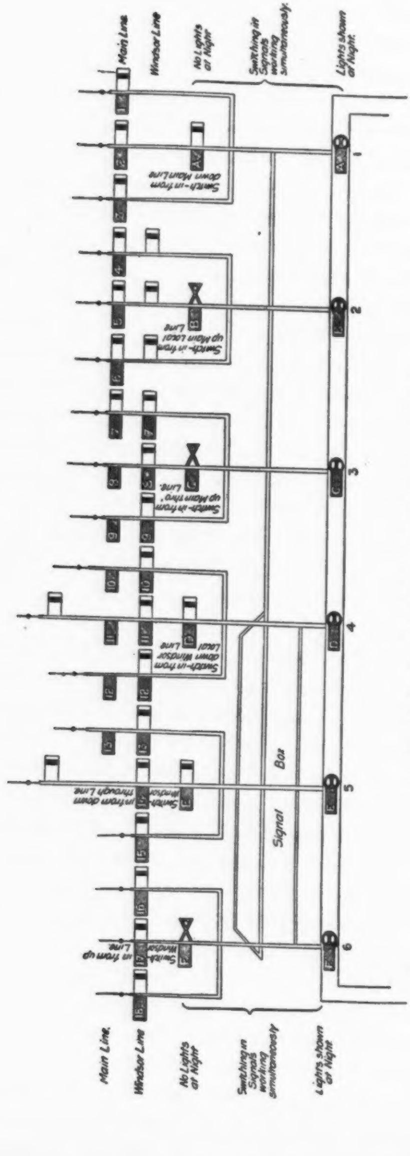
About 100 yds. from the "A" box down the line, a specially constructed signal bridge spans the six tracks, of which the railway from this point consists. This bridge supports the incoming stop, and switching and outgoing advance signals. From this point the signaling is taken up by the "B" box, some 200 yds. further down the line, where the station department may be said to end. At the "B" box the whole or any portion of the traffic can be entirely diverted by a system of cross-over lines with angle or "slip" crossings, and points from the main to the Windsor line, and *vice versa.* A signal bridge on the station side, worked from this box, controls the outgoing traffic, and a similar bridge on the Vauxhall side carries the incoming signals.

Special cross-shaped signals have been fitted to the signal bridge at Westminster Road Bridge to protect trains and engines when switching out of the station yard on the respective incoming tracks. These are worked simultaneously with the "wrong-track" signals on

the standard posts. When at "danger" these special signals show a red light, which must not be passed by incoming trains, as it indicates that a train is switching out on the incoming track. When at "caution" they show a purple light to the incoming train. The "wrong-track" or "switching-out" signals show a purple light for "track clear" for the train which is switching out on the incoming track. The cross-shaped disc ground signals near the signal bridge must not be passed when at "danger" under any circumstances. Fig. 2 (page 526) shows the arrangement of signals at the "A" box as seen from incoming or "up" trains, the arrangement as seen from outgoing or "down" trains being shown on a smaller scale in Fig. 1. Only the arrival signals governing the platform tracks are provided with white lights. Any other signal showing a white light must be considered a danger signal, as it will indicate that the signal has failed or the glass been broken. Signals are placed at the west end of the platform; at "track clear" they indicate that the entire platform track is clear; at "caution," that cars or a part of a train are on the track, and an incoming train must enter slowly; and at "danger," no train must pass, but light engines may back down past them to be coupled to their respective trains. Incoming light engines must call the attention of the signal men at "A" box by whistling.

In order that access may be easily obtained to the locks, the floor of the signal box is provided with a movable framed hatchway, and there is just sufficient room below the floor for a man to creep along. There are altogether fifty-one channels in which the locking bars slide ; the tappets from one row of levers pass below those belonging to the other set ; there are, therefore, two locking-bars in each channel. As explained previously, "Simplex" gear levers are arranged so that one signal lever operates three signals. The raised woodwork against which the signal man places his foot is so fixed that he can still work, although the hatchway may be open. The signal levers are colored differently for the different work they have to do, and each is provided with a plate upon which are inscribed the numbers of the other levers which precede it.

One of the most interesting features of the signaling at Waterloo is the system of electrical interlocking carried out by Mr. W. R. Sykes, of Clapham. The details are too complicated to allow of an exhaustive description, but the chief points of interest may be broadly indicated.



View of Signals on Main Bridge as seen from Incoming Trains.

FIG. 2.

It is well known that the block system is intended to prevent more than one train being upon the portion of the line between the two signal boxes. On many roads it is made a "permissive" system, so that more than one train may be allowed within a block at the same time.

Suppose A, B, and C to be three signal cabins upon a railway, then the Sykes system holds a train approaching box B until a preceding train has passed box C, out of the block C, leaving a clear block for the second train to enter. Suppose the second train has reached B, the operator in the B box could not put his signal to "line clear," because it is locked and controlled by a machine electrically connected in the box ahead. The man in the B box must therefore signal to C box, asking the operator there to unlock his signal lever, and this would not be done if the section were occupied. The Sykes electric interlocking apparatus is fitted in connection with the "out" or starting signals from the eighteen platforms at Waterloo station. The normal condition of all these signals is the unlocked position. Roads 1 to 7 (see plan) feed the out main line; roads 7 to 18 feed the out Windsor or local Windsor, so that three trains can leave the station at the same time—say one from No. 2, down the main line; one from No. 7, down the Windsor local; and one from No. 14, down the Windsor line.

The three down advance starting signals are controlled by B box, and these in their turn control the starting signal, so that when a train leaves the station and the signal man puts the starting signal to danger, it becomes locked and remains so until the train has passed over a treadle placed some distance ahead of the advance signal. The act of passing over this treadle puts the arms of the advance signal and the distant signal at the B box to danger; it also takes the "back-lock" out of the lever working the advance signal, at the same time drawing the attention of the signalman to the fact that this has been done by sounding an electrical trumpet or "buzzer." The signalman now puts back the advance signal lever; this action releases the platform starting signals, so that another train can be sent down to the advance signal from any platform which the signalman may desire. The advance signal cannot be again lowered until the signalman at the B box allows the first train to pass his stop signal, and restores the lever and signal arm to danger, and it becomes locked in that position by

the signalman at C box. The man at B box can then press his plunger and release the advance signal lever at the A box, and if he should forget that he has let a train pass to the advance signal the electrical "buzzer" will remind him as soon as the man at B box plunges to release the advance signal lever.

The signalman can, by means of the special "Simplex" gear lever, take the locks out of the platform starting signals and work his shunt signals in or out of the platform bays, up as far as the advance signal. With regard to trains coming into Waterloo, three trains can enter the station at the same time, namely, "up main local," "up main" and "up Windsor." Electric contact safety bars are fixed alongside the rails in each platform bay, so that when trains are standing upon them the "in" signals are locked if the train occupies the full length of the bay; but if it only takes up half the available space, then the first electric contact bars are free and the signalman in the "Crow's Nest," or "West box," can lower his signal half way, which indicates to the driver entering the platform that half the bay is occupied. The act of lowering the platform signals by the man at the "Crow's Nest" or "West box," releases the "in" signal at the A box by means of Sykes' special apparatus.

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ELECTRIC ROCK BLASTING—THE AMERICAN METHOD.*

By William L. Saunders, M. Am. Soc. C. E.

Read November 2d, 1892.

It is the purpose of this paper to describe and discuss modern American appliances for blasting rock by electricity. The matter is partly compiled from papers which the writer has from time to time published under "Notes on Quarrying" in *Stone.*

The importance of the subject can scarcely be overestimated, yet it may safely be said that there is no book which describes practically the best methods of blasting now in use in America. The various encyclopædias and some recent books, among them Eissler's "High Explosives," Drinker's "Treatise on Rock Blasting," André's "Rock Blasting," "Blasting," by Oscar Guttman, etc., are back numbers, and though useful in the line of history, adding to one's information, they are of no value as guides for the best practical work of to-day.

* Discussions received before January 15th, 1893, will be published in a subsequent number.

Since the invention of gunpowder the blast has played an important part in both engineering and industrial operations. Until recent years a blast in a drill hole was made by simply igniting a fuse which led to a cap which was inserted in a cartridge. Such a process as this is not only inefficient, but it is dangerous. It is inefficient because, under many conditions of work, the simultaneous discharge of blasts gives the best result, and it is dangerous because the fuse may hang fire. It would be difficult to conceive of a Hell Gate blast, or one of the large blasts recently made by Mr. Callanan at South Bethlehem, N. Y., without the aid of the electric battery. It is true that time fuses have been made, and are in use at the present time, but they cannot be relied upon under all circumstances, and especially when subjected to the varying conditions of damp holes in mines and quarries.

Persons who are using the electric battery for firing a blast are usually so convinced of its value that they are surprised when told that for this purpose the fuse is more largely used abroad than electricity, and that even in America a very large part of the work of blasting rock is done through the fuse.

The several improved forms of fuses which have been designed and used need not be described here. Some of them are made of cotton, others of hemp; some single tape, and others double; some of gutta-percha, and others of an outer and inner casing of special material made according to the conditions under which the fuse is to be used. At best, the fuse is inferior to the electric exploder. The exploder will do all that the fuse can do and more. If the work is of such a nature as not to warrant the expense of an electric outfit, any simple form of fuse may be used. In one point of comparison there can be no difference of opinion, and that is, the fuse cannot, at best, be as safe as the electric blast.

Electric firing was first introduced by means of static electricity, the current being generated by frictional, voltaic or electro-dynamic machines, or by other processes by which a current of high intensity but low quantity is generated. The electricity was discharged at the poles of two wires separated a short distance within a cap. The points of the wires were placed within a suitable priming solution and, as the current jumped from one wire to the other, this solution was ignited by means of the spark. The invention of this process dates back many years, and though several batteries have been made, notably those of

Farmer and Mowbray, yet the shortcomings of the process were so conspicuous that the electric blast only became popular when it became reliable through the use of the magneto-electric current.

In America nobody now thinks of any other kind of electric blast except that which depends upon the generation of a current from a battery, in a similar manner to the production of electricity for lighting purposes, this being used to produce incandescence in a wire which is submerged in an explosive. Static electricity has little or no heating capacity and cannot produce incandescence in a wire. The writer has seen a spark from static electricity jump through a common visiting card, leaving a hole, but no signs of burning. In damp places, static electricity may follow another course than that through the exploder, and many misfires occur.

The magneto-electric current is produced by the rapid revolution of an armature, or a coil of wire, at the poles of a magnet. In other words, the American electric battery is nothing more than a small dynamo operated by hand. The current is at first short-circuited in the machine, and at that point, when it is at its greatest intensity, it is discharged into the long circuit which contains the exploders. In this way the electric current passes over a fine platinum wire bridge, which offers so much resistance that the wire becomes red hot, and this heat explodes a small quantity of fulminate of mercury which is in the cap.

FIG. 1.

Fig. 1 illustrates the electric exploder. The wires *C* lead from the battery and are connected by the fine platinum bridge *E*. At *F* is a cement, usually made of sulphur, for the purpose of holding the ends of the wires intact and serving to seal the mouth of the exploder. *B* is the fulminate of mercury, which it will be noticed surrounds the platinum wire *E*. The whole is encased in a tube *D*, which is similar in appearance to a gun cartridge. The illustration is almost the full size of an electric exploder of average strength. The wires *C* should be of pure copper of about No. 20 wire gauge, and well insulated by cotton or other substance wound double. It is the usual custom to wind the cotton over the wire in one direction, and then reverse it, winding in the opposite direction, after which the wire is sub-

merged in a solution of paraffine or other waterproof substance. Two sizes of exploders are made, one known as single strength, and the other double strength. Those of single strength are sufficient for most purposes, and contain about 15 grains of fulminate of mercury. Where blasting is carried on under water, and wherever the explosive is gelatine, gun cotton, or forcite, the double strength exploder should be used. This also applies to high grades of dynamite, especially in cold weather; it being a well-known fact that dynamite requires a high detonation to ignite it properly. The greatest explosion that can be made by a dynamite cartridge is produced when the detonation is sufficient to insure the immediate explosion of the entire cartridge. Instances are on record where the exploder has been so small, that though it has been discharged in the mouth of a dynamite cartridge, yet the cartridge did not explode; and there are cases where a portion only of the dynamite was ignited, leaving an unexploded part of the cartridge in the bottom of the hole. Such dangerous and expensive conditions arise from too low a detonation from too small an exploder. This is so important a point that it should be made more impressive by further comment. In a large drill hole, where a number of cartridges have been placed, and where the drilling and charging has been a matter of time and expense, it is a wise plan to place two or three exploders in the hole. These need not be in a bunch, but had better be distributed at different points, so that the charge may be fired by simultaneous blasts produced by explosions at different stages from the bottom of the hole up. This is especially advantageous where the hole is damp, or where a very high grade of explosive is used. Some people of experience in the use of dynamite do not thaw it out in winter time, but depend upon a high initial explosion; and it is a fact that when dynamite is frozen it will not explode, except by a very large exploder. In some cases several ounces and even pounds of black powder are put in the hole in contact with the exploder and on top of the dynamite, in order to produce a large amount of shock and heat to discharge the higher explosive.

The passage of an electric current is practically instantaneous when compared with the transfer of heat through any substance. If several exploders are placed at different points in a charged hole, and are connected together in a series and fired by a battery, the explosion is prac-

tically instantaneous at all points in the hole. This cannot be the case where an exploder is placed at any one point, because, notwithstanding the fact that the ignition is rapid, there must be a certain lapse of time between the detonation of the fuse and the explosion of that mass of powder or dynamite which is located farthest from the fuse. It is well known that an explosion of powder is nothing more than the conversion of a solid into a gas. The gas occupies more space than the solid, hence in its tendency to expand it breaks the rock. Now, it is easy to see that the higher the grade of an explosive, the more sudden is its conversion into gas, and the more effective is the blow which it delivers in the drill hole. This is well illustrated in black powder, which is made of fine grain, or coarse grain, according to the work it has to do. The fine grain black powder will naturally ignite quicker and produce a more sudden conversion into gas, while the coarse grain will take time to ignite; hence, black powder of fine grain may be called a higher grade of explosive, and will do more effective work in rock than black powder of coarse grain. This question of suddenness of conversion into gas is at times more important than the number of volumes of gas produced by a certain number of cubic inches of the powder. A charge of black powder, when exploded in a gun barrel, has not sufficient suddenness of explosive effect to break the barrel, while an explosive of higher grade, like one of the dynamites, which, in quantity, may produce less gas, will break the barrel because its conversion from a solid into a gas was so sudden that the strength of the barrel was not sufficient to resist the blow.

The foregoing remarks show how important it is, in breaking rock under difficult conditions where high explosive effect is required, to explode the entire charge instantly, and also when using a high grade of explosive, to produce a high initial explosion. The placing of an exploder in different points of a charge is not a difficult matter. A dynamite cartridge is usually composed of a mealy substance which is enclosed in oiled paper. The best way to put in the exploder is to make a hole in the cartridge with the point of a stick, insert the exploder, and then by means of the thumb press the material around it so that it is thoroughly encased in the powder and will not easily pull out; then take a half hitch around the cartridge with the connecting wires. It is not good practice to use a

knife for opening the cartridge when putting in the exploder. Safety in the use of dynamite requires extreme caution, and sharp pieces of metal should not be brought in contract with the cartridge, except in cases of necessity. Take a piece of oak and whittle a stick to a point like that on a pencil, and it is better and safer than anything else that can be used for this purpose. Persons have had their fingers blown off through an attempt to straighten out an electric exploder with a penknife. If a man who handles the explosive is permitted to use a penknife at all about the powder house, he is sure to so far forget himself as to apply it in cases where some other and safer instrument is just as good, but which at the time is, perhaps, less convenient. The writer has no doubt that were the facts known in regard to the explosion of powder-houses, many cases might be traced to the use of the penknife by the single occupant of the building, who is usually blown to atoms.

An interesting experiment, which illustrates in a practical way the comparative effects produced by a slow and a rapid initial explosion, was made by Sir F. A. Abel, F.R.S., as follows:

"Three small iron cylinders of inch steam pipe, each being 5 ins. in length and having a cap screwed on one end, were embedded in the earth, with the open ends level with the surface.

"In the first was placed a charge of fine grain gunpowder, which was fired by an electric fuse, primed with mealed powder. The powder exploded with a dull report, leaving the cylinder in place and uninjured.

"The second tube contained an electric fulminate fuse, the remainder of the space being filled with sand. On firing this, the tube was bulged and cracked a little, but not moved.

"The third tube contained the same quantity of powder as was used in the first one, but it was fired by a fulminate fuse similar to that which was used in the second tube.

"In this case the report was sharp, the cylinder was torn to pieces, which were scattered about, and the earth in which it was embedded was thrown out so as to leave a considerable cavity."

There are many differences of opinion as to whether an electric exploder should be placed in the top, bottom, or middle of a charge. The writer's esteemed friend, Mr. Arthur Kirk, of Pittsburgh, is pronounced in favor of putting the exploder at the bottom of the hole, because of his desire to produce "the first point of rupture at the very bottom of every hole on the circuit at the same instant." There are others who claim that the exploder should be placed in the top of a charge, because it is preferable to break the rock at the top first and so relieve that at the bottom where the greatest resistance is

encountered. The writer thinks it is largely a question of what kind of a blast it is desired to make—whether the rock is to be broken for the sake of getting it out of the way, or whether it is to be dislodged in large masses for dimension stonework. Under ordinary conditions of work in mining and tunneling the exploder should be placed about in the center of the charge. Dynamite cartridges are usually made about 8 ins. long. If a hole takes three cartridges, put the exploder in the middle of the second one. If the hole takes a dozen or more cartridges, and the rock is very hard, with strong lines of resistance, the writer would advise placing two or three exploders in the hole, one at the top, another at the middle, and another at the bottom. Under ordinary conditions of mining, the holes are only about 6 ft. deep, about two-thirds of which from the bottom up is occupied by the explosive; hence, a single exploder in the center of the charge is sufficient, except where the dynamite is frozen, or gelatine, forcite, or other powders, are used which require a heavy detonation, in which case the double strength exploders should be used. If one is equipped with only the single strength, it is best to put two exploders in each hole, one of which may be a blank one, that is, not connected with the electric battery, but simply placed alongside the exploder to which the wires are attached.

In quarrying heavy dimension stone it is, perhaps, all well and good to put the exploder at the bottom of the hole, but even then much depends upon the nature of the stone. Dimension stone quarrying, where blasting is resorted to, involves great care on the part of the foreman. Dynamite or other high explosives have no place in dimension stone quarries, except for stripping. Low grades of explosives should be used, and as large an air cushion as possible should be left over the charge. A quick explosion is not desirable; on the contrary, a slow moving and accumulative force, when produced by an explosion, and when confined in rock, will, through its expansion, simply dislodge the mass. In such work as this it is a question of little importance, whether or not the detonation takes place in the top, bottom, or middle of the hole.

The claim which has been made that it is best to loosen the rock near the top of the hole first, has apparently some merit. In hard, compact rock it is possible to conceive a condition of things, where the breaking of the top of the hole by an explosion of the top of the

charge, might be advantageous in reducing the resistance which is encountered at the bottom. In blasting the "cut," for instance, in tunnel work, as much powder is used as in all of the side rounds com-

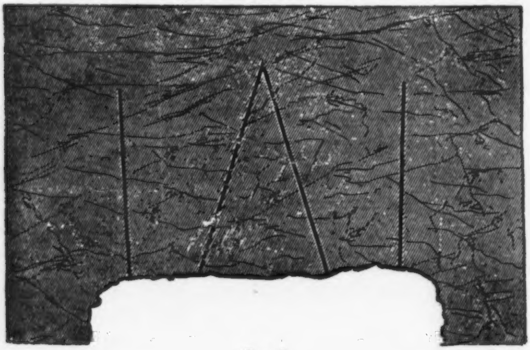

FIG. 2.

bined. At times the resistance is so great, that the highest grade of dynamite is blown out of the hole, and the hole is recharged several times before the "cut" is "thrown." It not infrequently happens that about half the hole is blown out and a second charge is required to break to the bottom; and it is only by such means that the "cut" is completely blasted out. Those who are not familiar with tunnel work can understand what is meant by this by referring to Figs. 2 and 3, the former being a horizontal section, and the latter a face view of a tunnel heading.

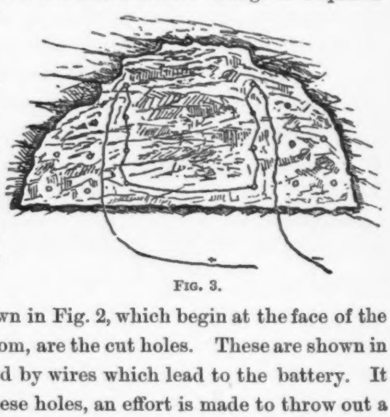

FIG. 3.

The converging holes shown in Fig. 2, which begin at the face of the heading and meet at the bottom, are the cut holes. These are shown in Fig. 3, charged and connected by wires which lead to the battery. It is obvious that in blasting these holes, an effort is made to throw out a wedge-shaped piece in the center. Where the rock is compact and hard, an explosion of tremendous force is necessary to overcome such great resistance. If we conceive a case where these holes are put in to a depth of 15 or 20 ft., which is seldom required, it is easy to under-

stand how difficult it would be to do any work at all by attempting to break from the bottom, without first throwing off some chips near the mouth of the hole, and an exaggerated case of this kind illustrates the reason for the claim that, under such conditions, it is advantageous to place the exploder near the mouth of the hole.

The common electric exploder is not water-proof, though it appears to be so. As previously stated, it has a copper case which is plugged with sulphur cement. Sulphur is used principally because it does not contract when cooling from a liquid to a solid state. But copper and sulphur expand and contract unevenly when under the influence of moisture and change of temperature. In a wet hole, especially where there is some pressure of water, the exploder may leak between the sulphur and the copper case, so that it is well to bear in mind, that, for wet work, exploders should be used which have been dipped in rubber cement or other water-proof material. Shoemakers' wax has been found to be superior even to rubber cement in water-proofing exploders. This wax, after being warmed, should be allowed to cool nearly to the consistency of jelly, before applying it to the exploder.

In connection with the manufacture of electrical exploders, much care should be observed to get them uniform. The bridge of platinum wire, through the incandescence of which the exploder is fired, should be exactly the same in diameter and length of wire in one exploder as in another; and as this wire is soldered at each end to the points of the wires which lead from the battery, it is important to use an uniform grade of solder, and to do the work of soldering by machinery, so that the same quantity is used in each case, and the soldering does not extend over the platinum bridge. If several electric exploders are connected in series, and it is intended to fire the whole simultaneously, it is obvious that if the platinum bridge in one is thicker than in the other, or is longer, or contains a surplus of solder, there will be an inequality in the resistance, which may result in failure to explode. Manufacturers who do not observe a thorough system of testing exploders before shipping should not be patronized. The test should determine, not only that the exploder is perfect in all its connections, but that it is uniform in electrical resistance.

In an electrical blasting outfit, the exploder is the key to the situation. It is a small thing, and must be a cheap thing in order to make it pay to use it, but it should be a reliable thing. No one can estimate

the disastrous results in loss of life and property which may be traced to a missed hole which had retained the fulminate cap. It is a dangerous operation even to attempt to take out the tamping with a scraper, yet some people are foolish enough to drill out a missed hole, thinking that they know just where the exploder is, and can stop drilling a few inches above it. Missed holes cannot always be traced to a defective exploder, but quite as frequently occur because an insufficient strength of current has been thrown into the line. The current must be strong enough to make the exploder bridge red hot, and there is no disadvantage in having it so strong that it will actually burn the bridge.

The wires attached to exploders vary in length from 4 to 20 ft. It is not necessary, as some may suppose, to have the length of exploder wire about equal to the depth of hole, but, with proper management, common connecting wire may be used with short wire exploders, thus saving money, because connecting wire may be bought at figures lower in proportion than the cost of long wire in exploders. Several rolls of connecting wire should always be on hand, and it can be used over again by saving the fragments after a blast, connecting them together and covering the joints. It is a curious fact, that all manufacturers of exploders make the two wires of exactly the same length. If the wires are longer than the depth of hole, there is no disadvantage in having them the same length, because, in connecting up, they separate at the mouth of the hole, and the two bare connections cannot touch. But it frequently happens that short wire exploders are used in deep holes, and in such cases the two wires run parallel with each other, the two bare connections being so close that they must either be covered with insulating tape, or carefully kept apart. Let one exploder wire be 3 or 4 ins. longer than the other, and the current cannot be short-circuited by the bare ends touching.

The question is frequently asked whether or not bare connections should be covered. With the old system of blasting, that by the current of high intensity, it was absolutely necessary to cover all connections; but the present American system uses a current of low intensity which does not spark or jump, but which will follow the best conductor, which is a copper connecting wire. In damp places the joints should be covered, because connecting wires are not always made of the best conducting material, and some little loss of current takes place when the bare wire is brought in contact with wet surfaces. The current

usually sent out from a blasting battery is not so strong that these losses can be suffered. Always cover connections where there is any chance for them to connect with metallic surfaces. Always cover connections which occur in two parallel wires in a drill hole, as they are liable to touch. It sometimes suffices to cover one of the connections only.

An illustration is given of the most popular form of tape used for covering connections.

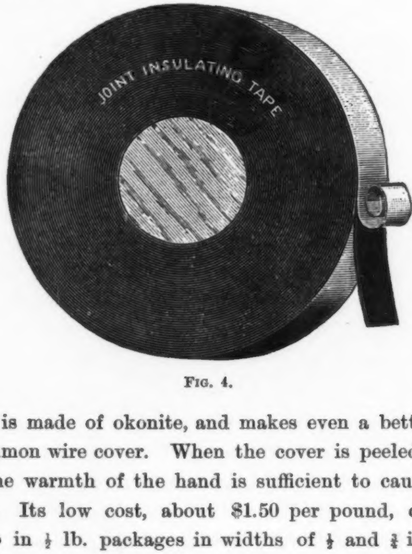

FIG. 4.

This tape is made of okonite, and makes even a better insulation than the common wire cover. When the cover is peeled off, the tape is soft and the warmth of the hand is sufficient to cause it to stick to the wire. Its low cost, about $1.50 per pound, commends it. It is put up in ½ lb. packages in widths of ½ and ¾ in., and when used properly, a pound of it will last for some time. It frequently pays for itself, provided it is used to cover joints made by connecting up the fragments of broken wires. Even short pieces may be made use of and used over and over again by properly covering the joints.

Making the joint is not so simple an operation as it appears. The first thing to do is to bare the wires; and if they are already bare, it is best to use a knife in scraping them, thus removing all oil or other material which may interfere with a perfect connection. Two points must be observed: one is, to bring the two wires in thorough contact with each other; and the other, to so connect them that they

will not easily pull apart. In order to do this, both wires should be twisted in the manner shown in the illustration herewith.

FIG. 5.

Bring the two ends together with both hands, and, by means of each thumb, twist alternately one wire and the other, and in this way they are not only brought in perfect contact, but they are tied together.

Connecting wire is usually made of copper, because of its high conductivity. It is important to have it of the best conducting material, so that the electric current will not be disposed to run into the ground, as it may do at exposed points. It is not an uncommon thing to make a blast with an electric battery, using a piece of bare copper wire laid in contact with the ground or rock; but as electricity always follows the best conductor, there is little or no current lost. However this may be, a covered wire is the safest, because, as previously stated, there is never too much electricity thrown into a blasting circuit, and the stronger the current, the more certain is it that each cartridge will explode.

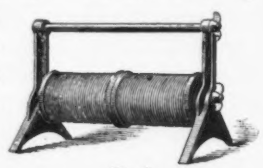

FIG. 6.

Figs. 6 and 7 illustrate two different forms of connecting wire holders with the spools attached. The holder shown in Fig. 7, when laid over on its side, as illustrated, is in position to wind up the wire, and has sometimes been used in this way to carry spools of leading wire. Either one of these holders is simple, cheap and useful. It is much better to follow a system which requires all the wires to be rolled on spools or reels after the blast, and thus to avoid the liability of losing time by tangled pieces of wire, and failures to fire caused by broken wire, kinks, etc.; besides, the reel is a means by which wire is saved. There are times during the day when some one about

the work can spare time to assort the several pieces of connecting wire, splice them together, cover the connections with joint insulating tape, and roll them on the spools to be ready when the time comes to blast. Be sure to make use of the wire which comes with the exploder, as the blast seldom destroys it all. It is about the same in diameter and in nature of material as regular connecting wire, and, with proper care, these exploder wires may furnish a supply of connecting wire.

Leading wire is used for the purpose of conveying the electric current from the battery to the connecting wire, and forms a very important part of a blasting outfit. About 500 ft. of leading wire is required for each equipment, and as two lengths are required, this would locate the battery 250 ft. from the blast. This distance is not,

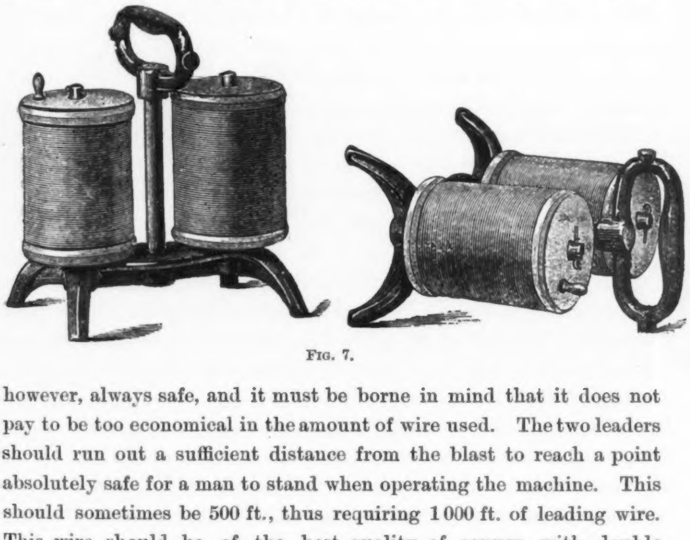

FIG. 7.

however, always safe, and it must be borne in mind that it does not pay to be too economical in the amount of wire used. The two leaders should run out a sufficient distance from the blast to reach a point absolutely safe for a man to stand when operating the machine. This should sometimes be 500 ft., thus requiring 1 000 ft. of leading wire. This wire should be of the best quality of copper, with double insulating cover. There is a standard furnished by all manufacturers of blasting apparatus, which should be the size employed in every case. A reduction of the size will reduce the efficiency of the current. No. 14 wire gauge is about the standard, braided with cotton, and water-proofed by being dipped in paraffine. It costs about one cent per foot.

An excellent form of such wire is a cable composed of two wires wound together except for about 30 ft. at the end, when they are separated so as to be connected at each end of a circuit. This cable is made by taking two well-insulated copper wires and binding them together by an additional insulation. The advantage of the cable is, that less delay is likely to arise by entanglement of wires, and time may be saved by having only one instead of two separate ones.

The rule should always be to use a leading wire reel, as it saves time and expense, and insures certainty in the electric connection. It is the worst kind of policy to have a tangled mass of wire to be a source of delay, annoyance and expense, when the blast is ready for the connection to be made. As the leading wire is heavy, it is apt to break if twisted too much; and as it is difficult to detect the break, it is sometimes advisable to put in a single exploder on the ends of the wire and test it with the battery.

There are many forms of reels in use for carrying leading wires. A good carpenter can make a satisfactory reel, and a good one can be bought for $4.

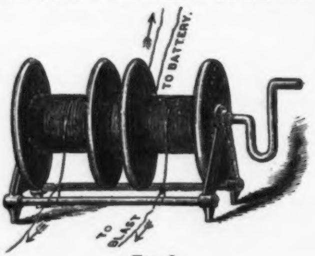

FIG. 8.

Fig. 8 shows a common form of reel. It is simply a cast-iron frame carrying two spools, around each one of which a wire is wrapped. One end goes to the battery, and the other to the blast. Another form of reel is a wooden spool mounted in a frame of wood, and provided with a handle and bearings for the spool. Some makers offer reels that are enclosed in a box. The writer's experience is that the simplest reel is the best. It should be open so as to be clearly understood and easily examined, in case any break is discovered in the circuit. Such a break must be traced, and the best place to begin is at the battery, following the wire to the blast.

The writer is not an advocate of the use of so-called blast testers. Some beautiful machines have been made and are sold for the purpose of testing the circuit. In some of them a flash is made to indicate that the circuit is complete, and in others a little bell will jingle. Those who sell them have a very strong argument when they claim that much trouble and expense is caused by finding out, when an attempt is made

to fire with the battery, that there is a broken wire or a defective exploder in the circuit, and that it had better be tested beforehand. It is certainly true that it is a great satisfaction to know that the circuit is complete, and that the blast is going to fire, before the battery is used; but the so-called testing machines do not always give such knowledge, and the delay caused by their use scarcely warrants the trouble. There is one great advantage in a testing machine, and that is, it can be used to test each exploder ; but the waste of time involved scarcely warrants a system of testing all the exploders.

The writer used a testing machine in some submarine work several years ago. It was one of the jingle-bell kind, and as there had been many misfires it was welcomed as a means by which he might not be further harrassed. Before every blast the testing machine was used, and with great joy it was noted that the little bell rang on every occasion. It happened one day that a blast failed to go off, although the tester had been used, and the bell had jingled as loudly as ever. To make sure, the tester was tried again with the same result. One of the leading wires was then cut in two with a knife, and the ends held apart in the water and the testing machine jingled away with great assurance. On examination it was found that the principle on which the testing machine was made was the generation of a current of low quantity which was not of sufficient strength to produce redness in the exploder wire, but was strong enough to jump through the water and ring the bell. The common battery which produces a current sufficient to ring a door bell on the push of a button, illustrates this point. This current is of very low voltage and would not set off an exploder, but so long as there is a reasonably good connecting medium its influence will be felt in the bell. Water is a fairly good conductor, and as water or moist places are common about blasting operations, it seems better to run the risk of having a break in the wire to be discovered by the failure of the battery, than to spend much time with a testing machine.

Let us suppose that a testing machine is reliable, and that the bell will ring only when the wire circuit is absolutely unbroken. Suppose we have a break and on applying the testing machine it is discovered that the circuit is not complete, we are now in exactly the same position that we would be in had we attempted to fire the blast by the battery, because if there is a break the battery will produce no

effect. The testing machine now comes in as a means by which we may trace the break, but in order to do this we must disconnect all the wires and test each hole separately. If the break is below the tamping, it is a dangerous operation to try to get at the exploder. It is in this way that the worst accidental explosions occur. It is far better to try to blast with the battery, and, if there is a failure, leave out one or more end holes. In this way some of them may be blasted; the others which fail to explode receiving attention afterward by an additional hole sufficiently removed for safety from those containing unexploded powder.

In nineteen cases out of twenty a failure to explode is due to a defective exploder, and not to a broken wire. In making this statement it is assumed, of course, that reels are used and care is taken to keep the wires in good condition. A defective exploder is a serious thing, yet the writer's experience is, that notwithstanding the fact that reliable manufacturers test all of their exploders, defects occur through corrosion, and it is absolutely impossible to make sure that exploders are perfect unless they are tested just before they are used. In this respect the testing machine comes in to advantage. The solder commonly used by plumbers will not do to join the platinum bridge to the two ends of a copper wire in an exploder. Lead and platinum do not do well together, because of the liability of corrosion, which results in breaking the platinum bridge; therefore, a lead solder should not be used with a platinum wire. The writer's experience is, that where due care is observed in looking after the wires and in keeping them in good condition, and where exploders are not stored away in damp places or kept too long a time before use, it is a very unusual thing to have a broken connection, except in difficult work under water, or where the rock tends to crumble and cut the wires.

The first thing to do after the battery has failed to fire a blast, is to see that the leading wires are properly connected to the binding posts of the battery; then to follow each leading wire through the reel and to the blast. See that the ends of the leading wires are properly bound to the ends of the connecting wires; then follow each connecting wire into each hole, taking care to observe that the joints are properly insulated. If the man who did the tamping used proper care with his wires, and if the exploders are in good condition, the break is sure to be found. If it is above ground there is no use of trying to find

it anywhere else, but it would be better to abandon some of the holes than to endanger human life by attempting to pry into them.

Common leading and connecting wire in the process of manufacture is pulled through a die to make it uniform in size, and the makers are sometimes careless about the connection of the two ends. When the end of a piece of wire is reached, another piece is simply put up against it with no more connection than that made by the woven cover. Unless the wire is tested before shipping, it cannot be relied upon; but every good manufacturer tests each piece that he sells, and even if a piece is shipped with one of these broken points beneath the cover, it is discovered the first time that an attempt is made to use it.

The battery is the generator which makes electric blasting possible. The American battery is as distinct from that of any other country as the American system of blasting is distinct and superior to any other. It is because of the reliability of the American battery that electric blasting has replaced the fuse so generally in America, and it is owing to the unreliability of batteries used in foreign countries that the fuse is still preferred there.

The American battery is a magneto-electric machine, that is, it is a hand dynamo, while the foreign battery is the old style friction machine which was tried and long since abandoned in this country. Frictional machines are injured by moisture, and are weakened in capacity by wear, it being necessary to give them constant attention; besides, the current itself is one of high intensity and little quantity, and it has little heating capacity. It simply sparks, and to use it with any degree of certainty, requires the most perfect insulation in damp holes, and in submarine work it is very unreliable.

The great advantages of the magneto machine are its reliability and indestructibility; it requires little or no attention, is simple in construction and light in weight. The low tension current which it produces does not spark and is not lost in damp places, requiring no special care in insulating all the joints, and thus adding very much to the reliability of the system.

In Germany the old Bornhardt machine is used. This, like all friction machines, involves the turning of a crank, storing a current in a condenser, and at a certain point discharging it by pressing a button. Other friction machines in use abroad are the Mowbray, Siemens and Leclanche. It is curious to note that Mr. H. Julius Smith, the inventor

of the first successful magneto-electric battery, began by constructing a frictional machine, which was at first used to a limited extent in America. This battery consisted of a wooden case about 12 ins. square and 6 ins. deep. A handle projected on the top of the case and was revolved horizontally. After attaching the leading wires the handle was turned a certain number of times in one direction and then turned a quarter of a revolution backward, and by this means discharged the condenser and fired the blast. This machine was less exposed than others, and less affected by moisture, and it was the lightest battery ever made, weighing only 10 lbs., but it readily gave way to the hand dynamo.

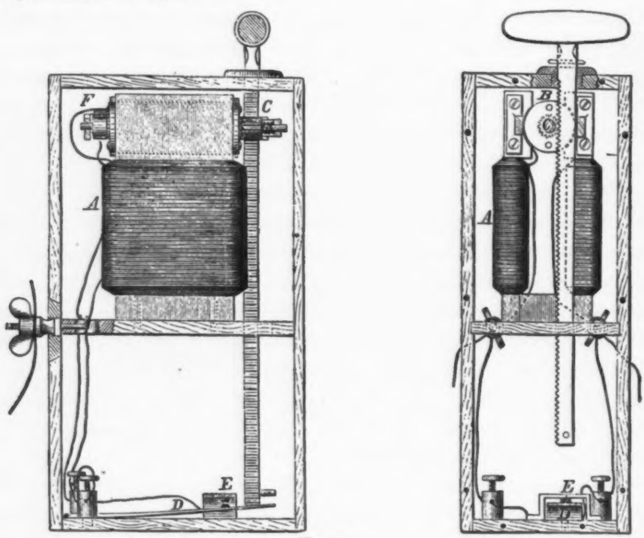

FIG. 9.

Fig. 9 illustrates the interior construction of the first successful magneto-electric blasting machine. This apparatus is the invention of Mr. H. Julius Smith, and is sometimes known as the "plunge" or "rack" battery. It is constructed on the principle of an ordinary dynamo in that it is an iron magnet of the horse-shoe character wound about with coils of insulated copper wire; between the poles of the magnet there is fitted to revolve, an armature of cylindrical construction, carrying in its body other insulated wire coiled longitudi-

nally as to the cylinder. The rapid revolution of the armature by suitable means generates and sustains in the machine an accumulative current of electricity of great power, which, at the moment of its maximum intensity, is switched off to the outside circuit in which are the fuses, and in the interior of each fuse the ignition is accomplished instantly.

A is the principal magnet. *B* the armature revolving between the poles of the principal magnet. *C* the loose pinion, its teeth engaging with the rack bar, and by a clutch also engaging with the spindle of the armature on the downward stroke (only) of the rack bar. *D* the spring, which, when struck by the foot of the descending rack bar, breaks the contact between two small platinum bearings, and causes the whole current of electricity to pass through the outside circuit—the leading wire and fuses. *E* the two platinum bearings, one on the upper face of the spring, the other in the machines as at present constructed, being a screw with a platinum point, passing through the yoke above the spring. *F* the commutator.

The points at which, after long use, failure is most likely to occur, and repairs may be needed, are as follows: the small pinion *C* by violent usage may break. A new one can be fitted with little trouble. The platinum bearings at *E* may be fouled by dust or other foreign substance; it is necessary that these should be bright and clean. Opening the case at the back, examination and cleaning if necessary, can be easily accomplished.

The "commutator" is a thin ring of copper like a section of a tube (or would be so were it not divided by a saw cut on each side into two equal parts) fastened upon a hard rubber hub. The "commutator" has pressing upon it (on the outer surface of the ring) two copper springs. These should press firmly upon it, and its surface should be bright and clean. In the course of time, particularly if the machine has not been used, this surface may become tarnished; then it will be necessary to make it bright. Rubbing with dry emery paper will serve this purpose; afterward the surface should be slightly oiled. Also, small particles of copper, the result of the wear of the ring or the springs may fall into the crevices between the two parts of the ring. If these crevices become filled with dust or copper, the result will be to weaken the effectiveness of the machine, as it is necessary that the two parts of the ring should be insulated.

In order to cleanse this ring or commutator, the rack must be taken out of the case, which can be done by removing the small screw near the lower end; then the interior working parts of the machine, with the shelf on which they rest, can be moved partly out of the case—far enough for the purpose. The parts being within reach, remove the springs which press upon the commutator, and the yoke which holds in place the spindle upon which the commutator runs, and the latter can then be readily cleaned and replaced.

This machine should never be exposed to excessive or long-continued heat; should not stand for over an hour at one time in the hot sun, or where the thermometer may show, say, 90° of heat. That heat which will melt sealing wax might be destructive to the machine.

Two sizes of the "plunge" battery are made, known as the "No. 3" and "No. 4." The capacity of the "No. 3" is about 12 holes, and of the "No. 4" about 25 holes, but many persons claim that they can fire a greater number of holes with the smaller "No. 3" battery than with the "No. 4." With a "No. 3" machine in good condition one is more likely to fire a larger number of holes than with the "No. 4," because of the resistance which the latter offers in pushing down the handle, and the difficulty in getting up speed enough in the armature to discharge a strong current. It is obvious that to get the best work out of the "plunge" machine, the handle must press down in a perfectly straight line without bearing either way and the greatest speed must be acquired at the end of the stroke. It is a difficult matter for anyone, no matter how experienced he may be in the use of these batteries, to discharge exactly the same quantity of current at each operation. To get the best result one should take hold of the handle with the right hand and lift it to its full length, then press it down, at first with moderate speed, but finishing the stroke with all possible force, bringing the rack to the bottom of the box with a solid thud. Some persons in using this machine give the rack a churning motion before pushing it all the way down. This is of no advantage whatever; on the contrary, it is likely to injure the machine, as by several strokes in quick succession enough heat may be generated to destroy certain parts. The current is no stronger, because there is no such thing as storing the electricity, the chief point being to get high speed at the end of the stroke.

Another form of battery used in America is similar to the "plunge," but is fired by pulling a rod or tape instead of pushing a rack. This is known as the "pull-up" machine. Its general construction is similar to the plunge, the chief difference, besides that already referred to, being in the method by which the circuit is changed. Instead of striking a key at the end of the stroke, the current is thrown from the short circuit of the machine into the long circuit containing the exploders by simply breaking the short circuit.

Fig. 10 illustrates a new form of battery known as the "Crescent"; its interior construction is shown in Fig. 11. It is distinctly different from all others in the method by which the current is discharged. In principle it is identical with the "plunge" or the "pull-up" so far as it consists of a magnet with an armature at the poles. In the "Crescent" this armature is revolved by a rack which is a segment of a circle. The power which generates the current is a strong steel spring, the operator simply pressing this spring to a point from which it is automatically released, and the current is thrown into the line at the end of the stroke by breaking the circuit, the rack and the pinion on the armature shaft forming a short circuit. This circuit is broken by the fact that the pinion and quadrant are separated within a short distance of the end of the stroke, and the current which had been produced, and which will in all cases take the shortest circuit, is now forced to take a path through the leading wires and exploders.

FIG. 10.

It is obvious that in all other blasting machines the strength of the current must depend largely upon the personal equation of the operator. This is shown by the testing lamp, which is a good

device to have around every blasting operation. It is nothing more than a common incandescent electric-light lamp except that it is made with a small wire connection, instead of the horse-shoe shaped one, common in light lamps. It rests on a small cast-iron stand, and can be procured at an expense of only $2 25, from manufacturers of blasting outfits. These lamps have short pieces of wire, by means of which they are connected with the poles of a battery. The battery is used in the regular way as it is when blasting, and the full stroke of the current is thrown into the lamp, lighting it up. With all machines, except the "Crescent," the light varies in intensity with almost every operation. Sometimes it is a dull red, then again

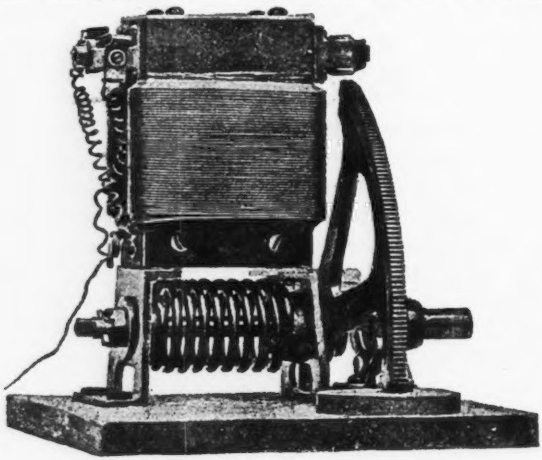

FIG. 11.

a bright white, according to the speed of the armature at the time the circuit was changed, which, of course, depends upon the skill of the operator. With the Crescent battery, on the contrary, no skill whatever is required; the operator must have force enough to press the spiral spring to the tripping point, when the battery will discharge exactly the same strength of current at each operation, no matter who may operate it. On the shaft of this battery there is a ratchet nut, which, when tightened, gives the spring more tension; hence, by adjusting this nut, not only may the capacity of the battery be kept up, but it may be set for any number of holes. The testing lamp shows a light from this battery of exactly the same intensity at each operation.

The rounded top of the Crescent battery is an advantage, in that there is no chance for moisture or drops of water to damage the machine. Where the handle is on top, water will sometimes work itself down into the parts and destroy them. The top is made of indurated fiber, which is not only light, but being a non-conductor of electricity, there is no chance for the current to be thrown into the operator, or lost in the ground. In all other batteries the operation is a violent one, but in this case it is just the contrary, the directions given being to move the handle slowly. After a blast has been fired, the handle is taken from the shaft and put away, so that the battery may be left in the mine without the liability of its being tampered with or damaged.

Uniform strength, or quantity of current at each operation, is an important factor in electric blasting. In the first place, it is important, as previously pointed out, to have a surplus of force in a battery. A common cause of misfires, where several holes are in circuit, is a weak battery, and—what is just the same thing—a weak discharge from a strong battery. A weak current will not produce sufficient redness in the exploder wires to make the blast, and as one exploder may differ in its resistance from another, a weak current sometimes discharges one or two holes, while the others do not go off, not because of any break in the connections, but simply from the fact that the little platinum bridge imbedded in the fulminate of mercury did not get hot enough. It is a curious fact that with several exploders connected in series a weak discharge will usually set off those nearest the poles of the battery. In other words, there are, say, ten exploders, all connected together, and through leading wires connected with a battery which is not strong enough to discharge them all, those which go off will be those nearest the leading wires, while those in the middle, or at the loop, can be discharged afterwards by changing the connections. If any one of them is discharged, it proves that the connections are all right, and that there is no exploder in the line that can be called defective. The fact that those which did not go off in the first operation may be set off when tried with a less number in the circuit is an evidence of the weakness of the battery, and it is needless to point out the danger and expense which might arise from such a state of things. The writer has experienced it frequently when attempting to blast a large number of holes.

Fig. 12 illustrates the whole operation of electric blasting, showing four holes connected in series, with the battery in the distance.

In blasting operations the importance of tamping should not be overlooked, and for this purpose tamping bags, made of paper, are very useful. They are furnished of varying sizes, corresponding with the diameters of the holes used, are from 12 to 30 ins. in length, and cost about $5 per thousand. It is much too common a thing for a foreman to use the handiest soil he finds for tamping holes, while much might be gained by the use of tamping bags filled at the proper time with the best tamping material. Dry sand is as good as anything, except per-

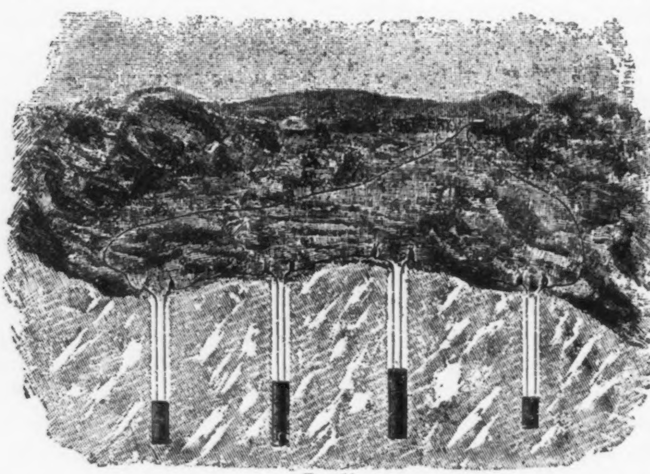

FIG. 12.

haps pebbles, and the worst thing of all is wet clay; though how common it is for wet clay or loam to be simply jammed into the hole with a stick!

The best tamping for a drill hole is that which is not like a cork—something to be blown out with a "pop"; on the contrary, it must be of strong, resisting character, something which changes form when disturbed, and which will tend to wedge. There are a great many patented plugs for tamping holes, but in no case can a plug, even with a wedging tendency, be strong enough to resist the force of the explosion. A wedging plug, such as inverted plugs and feathers in the mouth of a hole, is too expensive and involves too much delay

in its application; besides, there can scarcely be as much resistance offered by a solid plug of any kind as there is in a large quantity of small, disintegrated particles, which not only tend to wedge among themselves, but the disturbance of which creates friction through the mass.

In Europe dry clay is used with success, while in coal mines soft shale is used because of its accessibility. Broken brick moistened and the dust from the drill hole are frequently employed, and it is well to bear in mind that if things which are near at hand will serve the purpose they had better be used. This point can be determined by the quarry foreman, who should be sufficiently interested in the economy of the work to see that holes when blasted do not throw a large part of their force into the air. The writer has stood within 500 ft. of a blast, and has had broken pieces of stone almost as big as his head thrown around him, some of them having been sent up into the air 1 000 ft. Such reckless work is criminal, besides being expensive. The force generated by a blast should be confined within the hole, and there is no better evidence of the fact that it can be so confined than the work done in the upper part of New York City, where large blasts are made, directly in contact with the walls and foundations of buildings, without damage beyond an occasional tumble of plaster caused by the jar. The law has here taken the contractor in hand to such an extent that he has been compelled to tamp his holes carefully, and the result is that almost a perfect system of blasting is now in force among the better contractors, and not a single piece of rock is thrown during a blast.

Quarrymen will do well to look carefully to this question of tamping, as good tamping saves powder, is a means of safety and prevents destruction and waste of stone. When the writer began to blast rock under water he was told that water was a good tamping, and every blast should be made at high tide. He has learned by experience that the reverse is the truth. Water is the worst kind of tamping, except in surface blasting, where it is directly over the charge, or in drill holes, where the rock is perfectly sound and free from fissures, so that the water pressure is only on top of the cartridge and not around it.

It is obvious that a cartridge in a drill hole under water, unless it is plastic and fills the hole completely, is acted upon by the water pressure on all sides; hence the first thing which the force of explosion

has to do, is to overcome the hydrostatic pressure, and in doing this it loses a large amount of power before it strikes the walls of the hole. One-quarter of a pound of dynamite will do as much execution in dry blasting as one pound in submarine work.

When a drill hole is ready for tamping, it is best to use grass or a handful of rubbish of some kind first, so as to form something of a cushion at the top of the cartridge. This wad should be pressed directly on the cartridge, and no air space should be left, except in dimension stone blasting, where the Knox or other process is used. The harder the rock and the more thoroughly it is desired to shatter it, the tighter should be the tamping and the more closely should it press upon the cartridge. A rod of wood is best and safest for driving the tamping. At first the rod should be simply pressed tightly in the hole, but near the end it may be used with a hammer movement. In all cases be careful not to rupture the wires which lead from the hole. These wires should be held taut in one hand while tamping, so that there may be no tendency to kink. A projecting piece of broken rock in tamping is likely to cut the wires, though a careful operator may mix broken stone with sand and other material and make an excellent tamping without such cutting.

In some instances it is found desirable to discharge several hundred or even several thousand holes simultaneously. These cases are rare, and heretofore involved the construction of special batteries. Since the introduction of the electric light in mining operations, it has frequently been suggested that the light wires be used for blasting. In the case of a large blast there is nothing better for the purpose, and there is no doubt that another Hell Gate blast might be made with better success and at less expense by simply using the current from a dynamo.

In ordinary blasting operations it is not advisable to use the electric light current for blasting. There must be more or less danger connected with its use, and it is well to eliminate absolutely the blasting of rock from any such connection or association. A case has, however, come under the writer's notice, where the electric light wires are used with safety and success. This he can only attribute to the skill and care of the superintendent of the mine, Mr. J. A. Van Mater.

The mine referred to is that of the Sterling Iron and Zinc Co.,

Franklin Furnace, N. J. A sketch is appended (Fig. 13), showing Mr. Van Mater's arrangement, and it at once appears extremely simple. A switch circuit is taken from the main line, and five 16-candle power incandescent lamps of 109 volts each are cut in for the purpose of reducing the strength of the current to avoid fusing the connecting wires. At first only four lamps were put in the circuit to reduce the current, but it was found that the latter was still strong enough to fuse the connecting wire in the mine. This was because the connecting wire commonly furnished with exploders is small in diameter,

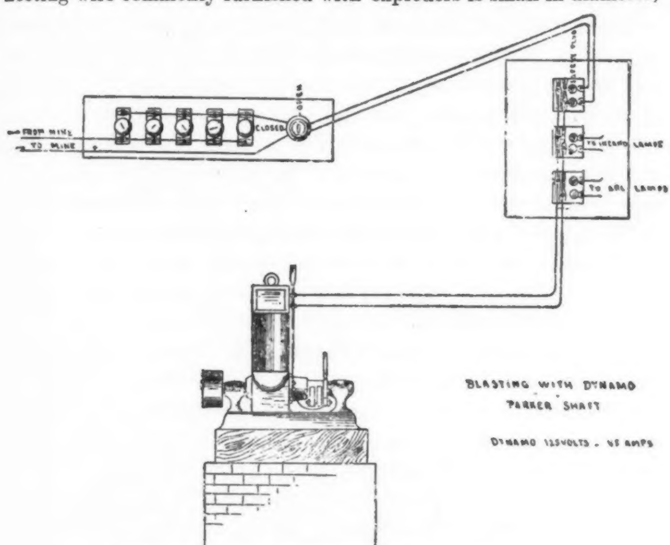

FIG. 13.

and offers so much resistance in the passage of a current. An additional lamp was cut in, and no further trouble was experienced. The wires are carried down the shaft, where they are connected to those of the exploders in the same manner as though connected to a blasting battery.

This plant consists of an Edison dynamo of 125 volts, 5 kilowatts, *i.e.*, ninety lamps of 16-candle power. Two arc lamps of 1 200-candle power each are used, equal to about thirty 16-candle power incandescent. Altogether fifty-four 16-candle power lamps are used out of an available 90-candle power, so that there is a large reserve capacity.

The switch shown in the sketch is always left open; but, in order to insure perfect safety, the plug marked "Safety Plug" on the sketch is always taken out and put away in a little drawer in Mr. Van Mater's office. If any one should go into the engine-house and turn the switch while the blast is being connected in the mine, it would not be possible to explode the charge. When ready for blasting, which, in this case, is determined by a count regularly made by the shift boss of all of his men, the engineer puts in the safety plug, turns the switch one-quarter turn, and the blast is made.

Though the greatest number of holes fired in the shaft by this plant is twelve, yet it is evident that there is current enough in the line to fire several hundred. A test was made with 40 caps, and all went off simultaneously. This blasting arrangement has been in use several months, and no misfires have occurred. Double strength, double insulated exploders are used. Before this plan was adopted a good deal of trouble was experienced, owing largely to the fact that the shaft is very wet. Mr. Van Mater suggests a separate circuit from the dynamo, that is, not the same circuit that lights up the mine. But this is very easily accomplished and is quite inexpensive.

Another point of interest about Mr. Van Mater's work at this shaft is that, notwithstanding many difficulties, they are sinking a shaft 10 ft. wide and 20 ft. long, taking out 8-ft. cuts, or 132 cu. ft. of solid rock with 129 lbs. of 60% forcite powder, or a little less than 1 lb. of powder to 1 cu. ft. of rock broken. This, of course, is very much higher than the record made in tunneling and open cut work, but it is well known among experienced persons that shaft sinking is not only the most difficult, but the most expensive, kind of rock excavation, submarine work only being excepted, and that in rare instances.

Rock excavation is by no means so costly as it was a few years since. Improvements have been made in the machinery for drilling, in the methods of blasting, in explosives, and in transportation machinery. Open cut work in limestone rock is, perhaps, the cheapest. Even in open cut work in New York rock, contracts are now let for less than $1 per cubic yard. A recent letting of more than 100 000 yds. of New York rock was made to responsible contractors at seventy-five cents per cubic yard. This work is in high bluffs, and it is likely that the contractor expects a profit from the disposal of the material.

The largest piece of rock excavation which has ever been let in this

country is the Chicago Drainage Canal. This, as let, is a thorough cut about 14 miles long and 160 ft. wide, and averaging 30 ft. in depth. Contracts have already been let for the removal of about 11 000 000 cu. yds. of rock, and the average price for rock excavation, delivered on the dump, is 79 cents per cubic yard. This figure is conspicuously low, because of the fact that the excavation of the canal involves the cutting of two channels the full depth of the canal, forming the banks. In other words, channeling machines must be used to make open cuts 160 ft. apart and for the entire length of the excavation. The intervening rock is broken by blasting, but the price, 79 cents per cubic yard, is for the whole work, and includes channeling. The contractors, in making out their bids for this work, paid little or no attention to the channeling clause in the specification, rating the cost of channeling at only from two to five cents per cubic yard of rock to be excavated. It is not likely that the contractor can make anything out of the disposal of the material excavated, as it is nothing but cheap, limestone rock, and there is plenty of it. The figures may, therefore, be taken as indicating the cost of open cut lime rock excavation in large quantities and under favorable conditions.

The writer has recently procured reliable figures based on ore bank blasting at the Croton Magnetic Iron Mines, Brewster, N. Y. Mr. Charles Vivian, who did the work by contract, is known to be competent and reliable.

Quantity and Cost of Mining at the Croton Magnetic Iron Mines from July 13th, 1891, to January 5th, 1892.

Total number of cubic yards of ore and rock mined, 9 295.

Drilling.	
Total number of holes drilled	238
" " feet drilled	2 988
Average number of feet per hole	$12\frac{1}{2}$
" " " per cubic yard	$\frac{32}{100}$

Expense.	
Total cost of labor	$5 696 00
Total cost of steam for drilling	212 13
Total cost explosives	755 35
Total cost repairs and supplies	139 00
	$6 802 48

Explosives.	
Total number of pounds dynamite used	4 083
Percentage of nitro-glycerine in dynamite	.52
Average number of pounds used per cubic yard rock removed	$\frac{44}{100}$

Cost per Cubic Yard.	
Labor	$61\frac{28}{100}$ cents
Steam for drilling	$2\frac{28}{100}$ "
Explosives	$8\frac{12}{100}$ "
Repairs and supplies	$1\frac{50}{100}$ "
	$73\frac{18}{100}$ "

This ore was mined and broken to 7-in. cubes and the waste rock to about 10-in. cubes. It is certainly an evidence of advance in rock excavating appliances that we may show a reliable case where ore was mined and broken into small pieces at a cost of $73\frac{18}{100}$ cents per cubic yard; this price including all expenses connected with the work, such as drilling, powder, block-holing, sledging, blacksmithing, repairs and supplies, and loading in cars. Most of this ore was broken when thrown from place, but a small block-holing drill was used for breaking up the large pieces.

In the Government work on the Harlem River the contractors are paid 93 cents per cubic yard for rock above the water line, and one of the contractors informed the writer that it has cost them 40 cents to drill, blast and throw it.

In a general way it may be said that open cut rock work costs from 3 to 10 cents per cubic yard for drilling, and from 15 to 30 cents per cubic yard for labor of blasting and explosives. These figures are based on drilling and blasting only and under fair conditions. The rock is simply thrown at the foot of the bluff.

It sometimes costs more to waste the rock, that is, to get rid of it, than it does to dislodge it. The location of the dump has a great deal to do with the cost of moving the rock. A dump close at hand and at a down-grade, is, of course, the most favorable.

Where the conditions will admit, a steam shovel is an economical device for removing rock. In order to use it the rock must be of such a nature that it will break readily and in small pieces, and the work must be uniform and continuous, like that of a railway or canal excavation. The delay caused by moving a steam shovel, to get it out of the way of a blast, is a serious obstacle to its use. In work where the bluff is steep and the drilling extensive, it is seldom necessary to blast more than once a day; large masses of broken stone are thrown a considerable distance in front of the bluff, and the steam shovel will work to advantage, as it may have a whole day's work ahead, without moving backward. The use of the steam shovel, of course, involves the use of cars, and it can only be used where there is plenty of track room.

For extensive open-cut work where a steam shovel cannot be used, the most economical device for handling the stone is the cable hoist. This hoist is of so much value and has recently been a subject of

so many improvements that it deserves more than a passing notice. Fig. 14 is an illustration of an improved form of horizontal cable-way. It will be observed that the two *A* frames or towers are located on the banks of the mine or pit. These towers are usually about 500 ft. apart and serve to support a main cable whose ends are securely anchored to the ground. The cable is a trackway for supporting a traveling carriage from which is suspended the hoisting rope. Two moving ropes are employed, one known as the hoisting rope and the other, used for the purpose of giving the horizontal movement to the carriage, known as the endless rope.

Fig. 15 is known as the inclined cable-way, and has been extensively used in slate quarries and in open-cut mining. It will be observed that the incline cable-way has only one tower, the other end of the cable being fixed in the bank. The incline cable is, of course, cheaper than the other, and it serves the purpose very well where the work will admit. It is not universal in its application and is not so thoroughly under the control of the engineer as the other form. Stops are placed on the cable at certain points where it is desired to have the carriage stopped in order to take a load.

Many improvements have been made in the details of the cable hoist, principally in the traveler and hoisting appliances. Good engineering is required in its construction. The largest span which has been used is that built for the Austin Dam, at Austin, Texas. This span is 1 350 ft., and the carrying capacity 6½ tons per trip. Another long span, 1 200 ft., is in use at the Edison Concentrating Works, at Ogden, N. J. The most important and largest application of the inclined cable-way is at the Tilly Foster Iron Mines in New York, where 600 000 tons of ore have been handled with these cables.

The following is the daily cost of transporting material on the cable hoist at the Beaver Asbestos Mines, Thetford, P. Q.:

No. of trips............................150 in 10½ hours.

Load averaging 1½ tons, or total of about 225 tons.

LABOR FORCE:	
1 Engine man..	$1 50
2 Truckmen, $1 each..................................	2 00
1 Tag rope boy...	50
7 Muckers, $1.05 each................................	7 35
	$11 35
FUEL AND SUPPLIES:	
One-half cord wood..................................	75
Oil, waste, etc	25
	$12 35

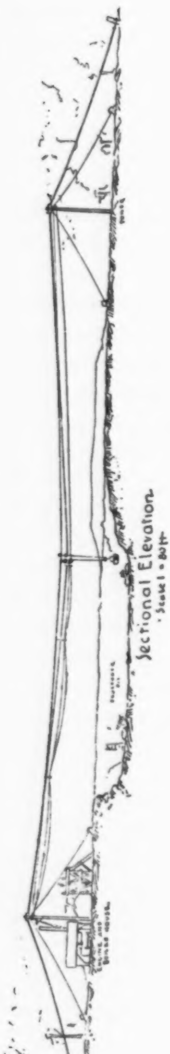
Sectional Elevation

Fig. 14.

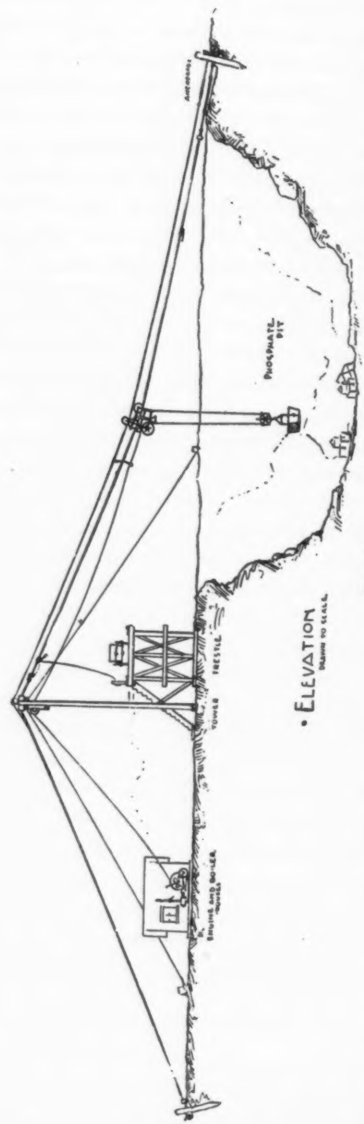
PHOSPHATE PIT
TOWER
TRESTLE
ENGINE AND BOILER HOUSE
ELEVATION

Fig. 15.

This makes a cost of 5¼ cents per ton, which includes raising and delivering at end of dump, 300 ft. from foot of derrick. The skips are mostly filled by hand, though some shovel work is done. Incline of cable, 30°; length, 225 ft.; pit, 50 ft. deep.

At the Tilly Foster Mines a comparison has been made between the cost of handling stone with a derrick and with a cable. The derrick was of the most improved pattern, and was swung by steam. The result of this experiment showed that the cable handled about 10% more material per day, besides extending across a pit over 400 ft. wide, while the derrick could only reach about 60 ft.

It is astonishing how general the belief is that dynamite acts downward. I have heard men who have been nearly all their lives in the powder business make the statement with all sincerity and belief that the direction of impact of a dynamite explosion is downward, and that in this respect dynamite differs from gunpowder or other explosives.

An agitation of this question was recently brought about by the Norcross bomb-throwing in Mr. Russell Sage's office in New York. The exact nature of the explosive which Norcross used is a mystery. It is certain that, although the explosive was of sufficient force to kill two men, blowing one of them out of the window, and to annihilate the interior of the office, yet no hole was made in the floor. The following are some of the expert opinions in this case.

Mr. George H. Benjamin is reported in the *World* as saying :

"It was not giant powder, nor black powder, nor gun cotton, nor nitro-glycerine. Each one of these explosives would have acted downward instead of upward and sideways. Had it been dynamite, a great hole would have been blown in the floor and poor young Norton would not have been blown out of the window.

"This man, probably, had a small tin or brass cylinder, or perhaps it was of glass, filled with fulminate of mercury. This is the material used in firing blasts, and is the base of all caps and cartridges."

A correspondent in the *Engineering News*, referring to Mr. Benjamin's explanation, argues as follows:

"There seems to be a general belief that the explosive force of nitro-glycerine or dynamite is always downward. My experience has been that it is exerted in exactly the opposite direction from that in which the primal force is applied; for instance, a cartridge charged with cap on top of explosive and with fuse pointing north, the greatest force of explosion will be in a direct line south. I believe that while the tendency of all glycerine explosions, in the immediate vicinity of the explosive, is to rend, tear, or, in other words, totally annihilate any

and all substances, yet the true explosive force which we wish to confine, direct or use will be found to follow a straight course, almost as if the same were confined within the diameter of a large tube, until its force is expended."

The *Engineering News* says editorially:

"We do not agree either with the theory advanced by our correspondent, or with that credited to Mr. Benjamin by the *World*. The ordinary law of the expansion of gases applies to all explosion, and the difference in effect between the combustion of black powder and the so-called high explosives, is due to the element of time in expansion rather than to differing components. When gas is generated it expands equally in all directions, and acts with equal force upon all surrounding objects. In reference to the "downward blow" exerted by high explosives, we may use the familiar illustration of "water tamping" in a rock blast. With black powder the generation of the gas is relatively slow enough to allow it to impart motion to the water, as resisting less than the rock, and the water is blown out. With the high explosives the expansive force is generated so rapidly that there is no time to move the water, before the power developed and confined by the water is sufficiently great to rend the rock. The fact that a hole was not blown in the floor of Mr. Sage's office may be ascribed to a certain elasticity in the floor, causing it to yield slightly under the blow."

The following view of the subject is given in the February Number of the *Engineering Magazine:*

"It must be confessed that, under the assumption that all the force of such an explosion is due to the expansion of the gas suddenly generated by the decomposition of the explosive, this view is unassailable. There are, however, those who, like the writer of this paragraph, deem it, at least, possible that there is something yet to be learned about the force generated in explosions of nitro-glycerine and dynamite, and it may be found that electricity plays a part in it. Whether the latter, or any one of the four different views relative to this explosive action be correct, their simultaneous existence is significant of the fact that its exact nature may be further and profitably studied."

Now, the fact of the matter is, that a high explosive like dynamite, if discharged from a balloon (that is, in a place where the resistance is equal all around), produces an effect equal in all directions. There is a proviso, however, which must not be lost sight of, and that is, that the explosive must be uniform, not part wet and part dry, or part one kind of explosive and part another, but absolutely uniform throughout its mass. It must also be exploded by a cap or detonator that is sufficient to create an explosive effect simultaneously throughout the mass. Take the illustration of a quantity of gas mixed with air in the body of a balloon, and if it is exploded it will discharge a volume of gas in all directions, pushing the outside air out of the way; or, in other words, tending to produce a vacuum in the

space occupied by the balloon. The difference between a gas or powder explosion and that of a cartridge of dynamite is simply one of degree. The dynamite is more quickly converted into the gaseous state, hence its action is rapid. Put a cartridge of dynamite on the ground and explode it, and a hole in the ground will result. Black powder in larger quantity and with more explosive force will go off with greater shock, perhaps, to the neighborhood, yet there will be no disturbance of the ground. This is not because dynamite breaks down any more than black powder does, but because the dynamite was converted into a gas so suddenly, that before it had a chance to expend its force in the air, it produced an effect and used up a portion of its power in the ground. To further illustrate this point, let us imagine a mass of compressed rubber resting on the ground; let this be a ball, and let us assume that it is compressed equally in all directions. If the string, or whatever is used to compress it, is suddenly cut, the ball will expand equally in all directions; but where it touches the ground it will meet with resistance which will result in a slight bounce, but it is not likely that the ground will be disturbed. An explosive acts in the same way, and when that explosive is dynamite its bouncing tendency is so great that it acts like a blow from a sledge, and a hole in the ground is the result.

One of the mysteries of a dynamite or powder explosion is why it sometimes creates such disturbance and destruction in one direction and not in another. We often hear of windows being blown out and buildings destroyed several hundred or even thousand feet from the point of explosion, while at some points very near it there is no disturbance. The writer has known trees to be blown down 1 000 ft. away in one direction, while 50 ft. away in the other the long grass and small bush were not affected. The explanation of this is simple. An explosion is a force which is governed by physical laws, and which may be likened to the laws governing the movement of a billiard ball. We know that when a billiard ball strikes a cushion at a certain angle it will leave the cushion at the same angle, that is, the angle of incidence is equal to the angle of reflection. An explosive force is first deflected by the ground, or whatever it may stand upon. This produces a concentration of force in an upward direction. In other words, the force which originally tends to act in all directions is now suddenly deflected. This ground may be soft in one place and hard in

another, or it may be irregular in structure, or it may not be level. All of these things tend to deflect the force. Then, again, the condition of the atmosphere and the position of buildings, trees, etc., all tend to cause the force when once produced to bounce as it were, in its tendency to expand itself fully in the line where it meets least opposition. The blast from the mouth of a cannon illustrates this point. The powder, being confined, meets with resistance in every direction but one, and the result is a concentration of force in the direction of the muzzle.

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(Vol. XXVII.—November, 1892.)

CONSTRUCTION OF A CHEAP DAM ACROSS THE ROANOKE RIVER, NEAR SALEM, VA.*

By OSCAR SAABYE, M. Am. Soc. C. E.

READ OCTOBER 19TH, 1892.

The Roanoke is not a very large river, its greatest width is not over 150 ft.; but it is a mountain stream, fed by numerous smaller creeks and brooks coming down the mountains, and (as all such streams are) is very treacherous and at times also very dangerous. In the spring and fall, when heavy rains occur, the Roanoke River often overflows its borders. The waters rushing down from the mountains at such times, with a heavy fall and great velocity, carry everything in their path with them, and do great damage to the surrounding country.

At Salem, Va., near the location of the dam described in this paper (see Fig. 1), the river makes a big bend, the water coming around with a very swift current. The fall here is quite heavy, at some places over 1 in 100. In the middle of the river in this

* Written discussions received before January 15th, 1893, will be published in a subsequent number.

bend is a small island which splits the current and throws the greater part of it toward the north bank, which is from 15 to 20 ft. higher than the south bank. The consequences are that the waters are thrown back to the south bank with great force, overflowing the bank and the country adjacent. The mill, as located on the plan, has been there for the last hundred years. There has also been a dam across the river for the same length of time. This dam has been washed away several times, the last time about 10 years ago, leaving the part *AB* (Fig. 1), standing in fairly good condltion, and an opening from *B* to the south bank of the river about 65 ft. wide.

The present owner of the mill and surrounding land decided to rebuild the dam and repair the old part, so as to utilize the great amount of water-power the river affords at this point. The height of the old dam was about 5 ft. over the average water level of the river. By rebuilding the dam to this height a water-power of between 500 to 600 H. P. could be realized, a natural and easily obtained motive power, well worth putting to use.

The owner came to the writer last fall, asking him if $3 500 would cover the repairs to the mill and machinery, the old dam still standing, and the rebuilding of the part washed away. If the writer thought it could be done for this sum of money, he would be authorized to make plans and go ahead with the work. Although knowing the location and the Roanoke River well, the writer replied that he could not say anything until after a careful examination of all conditions. He proceeded to make such an examination, and reported that he thought $4 000 would cover all expenses. Upon this report as a basis he was told to go ahead, but under no circumstances to exceed this sum, of which about $2 500 was intended for the construction of the new dam.

The object in view was, then, to build a cheap dam, at the same time one strong enough to withstand the force of the waters.

Two thousand five hundred dollars was not a very large sum for a dam to span an opening of 65 to 70 ft. wide in a dangerous and treacherous mountain stream, with about 10 to 12 ft. of water where the dam was to be built.

The proverbial "Oldest Citizens" of the place furthermore persisted in stating daily that no dam would or could stay there; that the bottom was rocky and very uneven, and that they had seen many dams washed away.

Last January borings and soundings of the river bottom were made. The appliances used for this purpose could, of course, not be very expensive. A pointed iron rod, driven down by a sledge hammer, was all that was used. The greatest depth of the water was then 10.5 ft. The bottom appeared to consist of rock with an overlaying stratum of river gravel, varying from 6 ins. to 2 ft. 6 ins. in thickness, the thickest part nearest the south bank. Although the soundings were taken close together, it was impossible to ascertain to a certainty whether the rock was solid or composed of big river boulders, which, to a great extent, form the bottom of so many mountain streams. By comparison with the river bottom about 100 ft. below the location of the proposed dam, where the rock was perfectly solid, I was led to believe the same would be the case where the dam was to be built. A profile of the bottom from the soundings is shown in Fig. 2, page 571. It will be seen from this that the bottom was uneven, with a comparatively deep hole nearest the old dam, and then gradually rising toward the south bank.

As the cost of the dam was so strictly limited, the writer decided upon the crib form as the cheapest, and, under the circumstances, also the strongest. Details of the construction, as the dam was built (with very few alterations), are shown in Figs. 2 to 7.

On account of the formation of the bottom and its unevenness, it was out of the question to frame the crib on land and then sink it. The dam would have to be built by the help of a coffer-dam, so as to lay the bottom bare. In case the belief that it was solid rock was correct, this would have to be leveled off, and iron rods inserted running through the timbers (Fig. 2). If the rock was only large boulders, they would also have to be made as level as possible, and the bottom timbers placed squarely on them. In both cases we had to make the river bottom dry and bare before beginning construction, and the dam must be built gradually from the bottom upward. At *B*, Fig. 1, where the old dam ended, was a piece of pole dam about 35 ft. long (Fig. 2), which, if good and solid, was to be used in connecting the new and old dam. This connection was rather the weak point, as it was close to the edge of the 10-ft. deep hole, through which the water now swept very swiftly, and, after the dam was constructed, would produce the greatest pressure. This piece of pole dam was left partly submerged from the time the other part of the dam washed

away. To ascertain the soundness and solidity of these poles it was also necessary to have the water around them pumped out. On the south bank of the river, about 25 to 30 ft. from the water's edge, the ground rises up to the proposed height of the dam, and the writer decided to tie the dam into this bank, building it exactly in the same manner as in the water, filled in with stones, and of the same width (16 ft. out to out), and going down in the ground sufficiently to prevent the water from undermining.

To prevent the water from washing out the bank into which the dam was tied, and from washing around the dam, it was decided to build a bulkhead along this bank for about 50 to 60 ft. to the same height as the dam (Fig. 1). This bulkhead was to be built of round or square logs forming a wall toward the river and tied into the bank by cross-pieces, spaced 5 ft. apart. The whole was then filled with stones for a width of 6 ft., starting at the same depth as the dam on land.

As will be seen from Figs. 2 to 7 the dam is a crib, composed of 12 x 12-in. white oak timbers, tied together by 6 x 12-in. white oak cross-stringers, placed 3 ft. center to center, of which the two bottom rows protrude 4 ft. outside the crib, so as to hold the upstream rip-rap in place and also to strengthen the dam. The crib is 16ft. wide out to out, filled in with good heavy stones, placed carefully and with as small openings between as possible. On the upstream side the crib is sheeted outside with 1-in. white oak planks in two layers, breaking joints, from top to bottom. During construction the plan was altered, the piece of planking marked A B (Fig. 4) on the downstream face of dam being done away with. The rip-rap on the upstream side was started with a 15-ft. base.

In case we struck solid rock bottom, there were provided 1¼-in. wrought-iron anchor rods let into the rock 18 ins., placed through the 12 x 12-in. sticks on each side of the crib, and spaced 5 ft. apart (Figs. 2 and 6). Furthermore, the specifications called for a layer of best quick-setting Portland cement in the bottom 4 to 6 ins. thick.

Some legal difficulties arising from fears of damage to the property south of the river which might be caused by the back water from the dam, delayed the beginning of construction until the month of June, which afterwards proved beneficial to the work, as the spring was rainy and the water in the river unusually high.

Actual work began the first day of June last, by starting the coffer-

dam. After the upper side of this was nearly completed, a heavy rainstorm with high water occurred, nearly washing away all the work done on the coffer-dam and 4 to 5 ft. of the south bank; this latter by the contractors' fault, in not running the coffer-dam far enough in on land. A second time the coffer-dam nearly completed was washed away within the next eight days. Finally, dry weather set in and the coffer-dam was finished without further mishap. It was built the last time very strong, of crib work, about 6 ft. wide, filled in with stones and puddled outside. It proved efficient, and no leakage occurred during the construction of the crib. At first, a steam pump with 6-in. suction pipe was put at work to pump out the water, amounting to about 148 000 galls., but it proved inadequate and a second pump also with 6-in. suction pipe was put on.

After the bottom nearest the south bank was laid bare, it was found that numerous small springs were running here, and it was necessary to put up a small dam inside and across the coffer-dam. On removing the water the bottom proved to be composed of large river boulders, the supposed rock the sounding rod had struck. The anchor rods had to be abandoned, and the bottom timbers were set down upon these boulders, as level as they could be made. The cement was applied under the timbers and inside the crib to prevent leakage. The 6 x 12-in. cross pieces were run alternately instead of right over each other.

The old pole dam was found solid and strong, and good connection with it was made on top of the poles. Good hard gravel bottom was found on land on the south side, down to which the dam and bulkhead were brought to a solid bearing, and the whole construction was finished in about twenty working days from the completion of the coffer-dam.

The contract price and actual cost of the whole work according to plans and specification was $2 400, with no extra allowances.

The author would say that he does not consider this as a remarkable piece of work, but its construction as described, taking into consideration the solidity and amount of work done for the small sum of $2 400, seems to him so very cheap, that he thought an account of it might not be without interest to members of the Society.

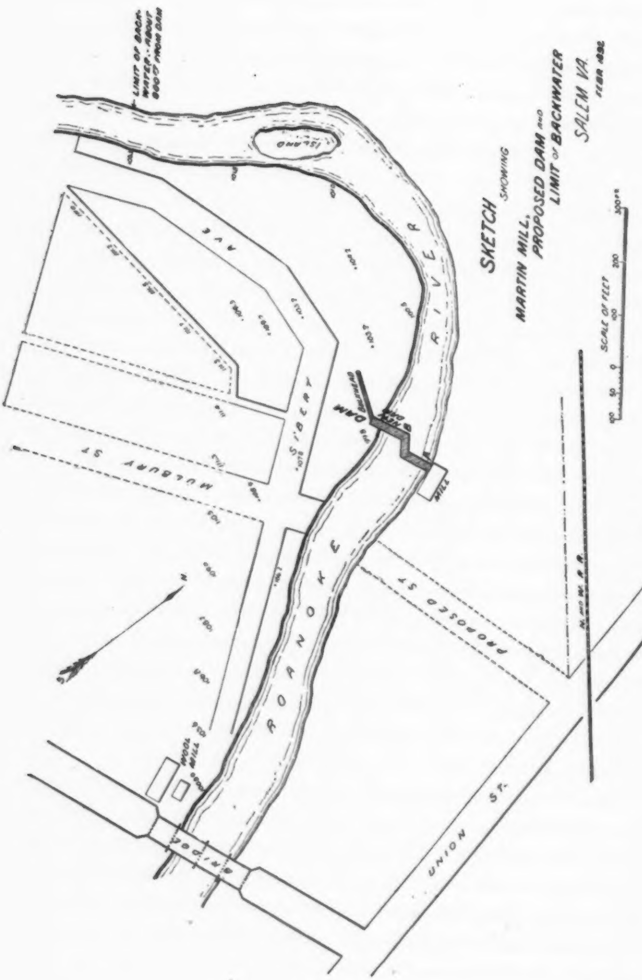

SKETCH SHOWING
MARTIN MILL, PROPOSED DAM AND LIMIT OF BACKWATER
SALEM VA.
ROANOKE RIVER
ISLAND
MULBURY ST
UNION ST.
PROPOSED ST
AVE
MILL
DAM
N
SCALE OF FEET

FIG. 1.

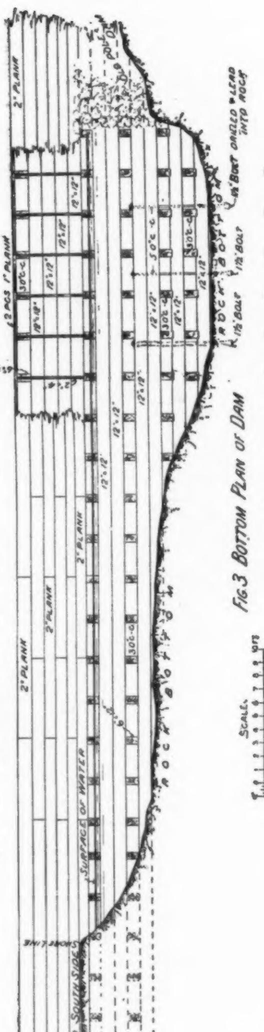


FIG. 2. PROFILE OF RIVER BOTTOM SHOWING ERECTION OF DAM

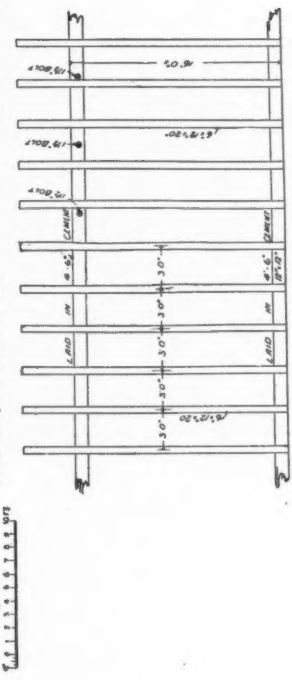


FIG. 3 BOTTOM PLAN OF DAM

BILL OF MATERIAL

51 PCS.	12" × 12" × 18' =	10200 FT. B.M. IN LENGTHS	18'
60 "	6" × 12" × 20' =	7200 "	20'
20 "	6" × 12" × 16' =	1920 "	16'
20 "	6" × 12" × 17' =	2040 "	17'
20 "	2" × 4" × 7' =	94 "	14' (10 PCS)
350 SQ. FT.	2" × 12" PLANK	700 "	14' TO BE CUT IN TWO
2900 " "	1" × 12" "	2900 "	12'
	TOTAL	25054 FT. B.M. VA. H.P. OR W.O.	

500 CB. YDS. ROCK
400 DRIFT BOLTS 7/8" × 18"
102 SCREW " WITH NUTS 7/8" × 12"

FIG. 4 CROSS SECTION

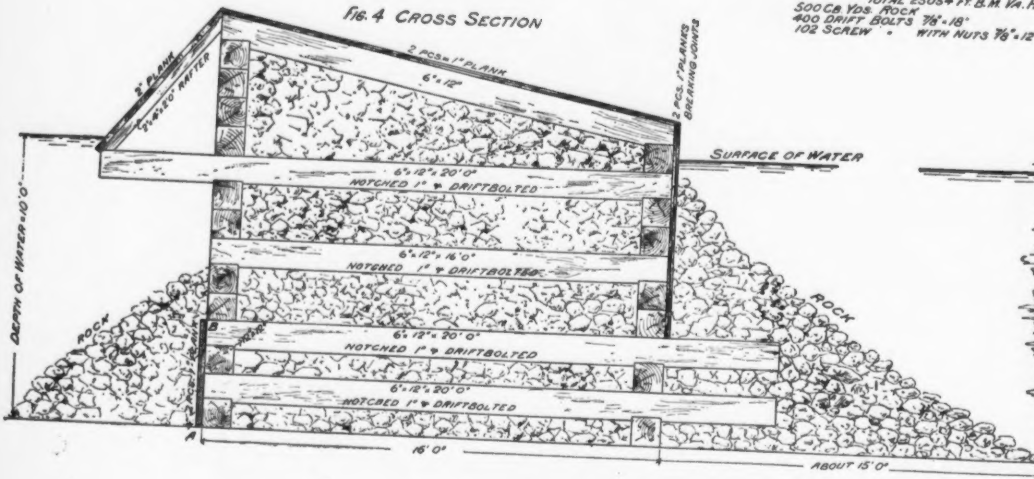


FIG. 5 FRONT ELEVATION

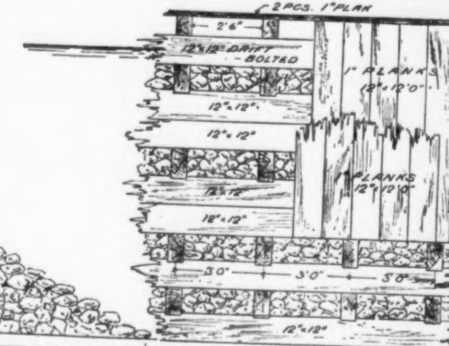


FIG 6 JOINT OF 12"×12" - BOLTS COUNTERSUNK

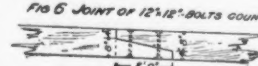
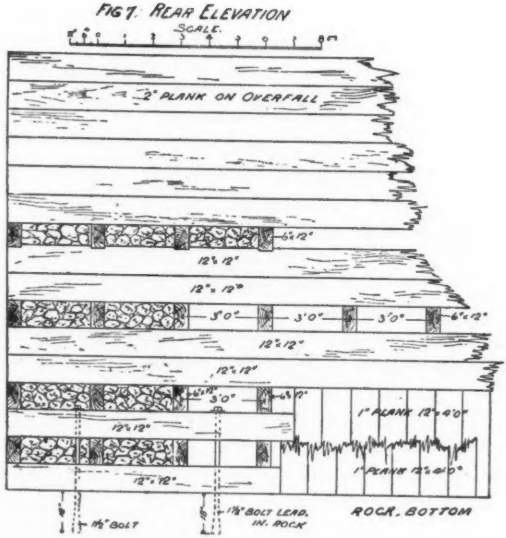


FIG 7. REAR ELEVATION



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(Vol. XXVII.—November, 1892.)

DISCUSSION ON MOTIVE POWER FOR STREET RAILWAYS.*

By E. N. Kirk Talcott, H. W. Brinckerhoff, Robert L. Harris, Arthur P. Dodge, C. E. Emery, W. H. Breithaupt, E. E. R. Tratman and Alfred F. Sears.

E. N. Kirk Talcott, M. Am. Soc. C. E.—In the paper which Major Sears has submitted to the Society he undoubtedly shows a vast amount of careful, painstaking research upon a subject which is of great importance in every city of the United States, and which has never yet been satisfactorily settled, and, as he himself says, probably never will be. The best that can be done under such circumstances is to get all the light possible upon the subject, and even then each locality must choose for itself the system best adapted to its particular surroundings.

The fact that each prominent city in the country is continually changing its motive power for street railways shows of itself that no motive power has yet been found which is satisfactory.

* See Paper No. 549, Volume XXVII, page 313.

So far as I am individually concerned I am free to say that my own prejudices are in the line of cable roads. This undoubtedly arises from an experience of several years with the South Side Street Railway of Chicago, where the service was excellent, and the stock could not be bought except at large advances above par. But, so far as any professional information is concerned, either as to cost of operation, or amount of power expended to produce the results, I must confess almost total ignorance. My prejudices are based entirely upon practical results. And yet they are quite largely supported by the adoption of this method of locomotion very largely in New York City on the Broadway, Third Avenue and other lines.

There is no question in my own mind on the electric motor for street railways. So far as I have been able to observe its operation, and I have studied it in several locations, it is unsightly, expensive, and not entirely reliable. The amount of power wasted in any electric system which I have ever yet seen would, of itself, condemn it.

I think that Major Sears has struck the keynote in the whole problem in the direct application of steam power for this purpose. If this can be proven to be practicable, on the lines which he indicates, I have no doubt that it will be the coming power, and I can now see no reason why it should not be a success. The accompanying paragraph,* cut from a New York paper, shows that Chicago, the most progressive city in this country, is already experimenting in the line indicated by Major Sears. If the direct application of steam can be made a practical success, there is no doubt in my mind but it will drive out all other power for this purpose.

H. W. Brinckerhoff, M. Am. Soc. C. E.—As this paper deals mainly with the cost of various methods of street railway traction, some figures compiled from the report of the Birmingham Central Tramways Company, Limited, of Birmingham, England, for the year ending June 30th, 1891 (see page 576), may have some interest, in spite of the fact that I am unable to give the length or character of the routes or other data that might help to a more intelligent understanding of the figures, the most interesting point being that one company operates street cars in one city, both by locomotives, horses, cables and electricity, the latter, as I understand, being used in the form of

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* The North-Side Street-Car System of Chicago is about to abandon the horse as a motive power and adopt a steam motor, several kinds of which have been tried lately.

storage batteries. It should also be remembered in comparing these latter figures that the electric department had only just been started and had been in operation but eleven months.

The figures, both as to cost and revenue per mile run, it should be noted, are very favorable to the cable system, and their chief value lies in the fact that these various lines were operated in the same locality and under the same management, and therefore their comparison is presumably fairer than could be made under more dissimilar conditions.

It should also be noted, in regard to the horse department, that it includes both tramways and omnibusses, the proportion of the former to the latter being in miles run about 1 to 4, and in passengers about 1 to 2½.

The report says: "Taken as a whole, however, the shareholders may view the year's working with satisfaction. The cable lines have more than maintained their earning capacity, and the electric lines, which in the first half of the year were suffering from exceptional difficulties of construction and maintenance, have apparently overcome these difficulties, and show a substantial profit, which is steadily improving."

From the Annual Report of the Birmingham (Eng.) Central Tramways Company, Limited, for the Year Ending June 30th, 1891.

Department.	Total Receipts.			Miles Run.	Passengers Carried.	Average Cost per Mile Run.							
						Motive Power.	Repairs to Vehicles.	Traffic Expenses.	Permanent Way and Buildings.	General Charges.	Total Cost.	Total Receipts.	Net Revenue.
	£	s.	d.			d.	d.	d.	d.	d.	d.	d.	d.
Steam	77 337	16	10	1 184 401	14 242 827	6.38	.33	1.63	1.55	1.05	10.99	15.67	4.68
Horse	29 276	15	2	637 724	3 752 416	7.33	.54	1.26	.14	.52	9.79	11.02	1.23
Cable	27 961	3	5	522 876	5 241 362	3.36	.83	1.30	.13	.71	6.33	12.83	6.50
Electric	8 732	1	8	138 396	1 144 718	5.44	1.93	1.34	.14	1.05	9.90	15.15	5.25

Robert L. Harris, M. Am. Soc. C. E.—I have read with much interest the paper by Major Sears, and am pleased that this subject has been prominently brought before our Society. Its importance should induce a beneficial discussion by members now engaged in city transit.

Between the years 1862 and 1865 I had in charge, among other enterprises, the construction, etc., of the first horse railways built in San Francisco, Cal. These were all very well on the level and slightly undulating sections of that city, but when it came to traversing hills (which were embraced in the charters), although not by any means the steepest in the city, yet with grades of 1 in 10, it seemed cruelty to animals to ride up such ascents, even with doubled-up teams, while the coming down was at first perilous to both animals and passengers. About the year 1868, I devised plans for a cable railway, indicated a route over the hills, and tried to induce some friendly capitalists to obtain a charter. My efforts were unavailing, but a couple of years thereafter a cable road was built, and was successfully operated, after which several were constructed, and have proved profitable and very convenient for that city, so much so, that the example set by the city at the Golden Gate was rapidly followed. I returned a few years ago from a visit to the Pacific coast, with the opinion that for cities with steep hills this was the best method yet known. The results of extended personal investigations a few years previous to the visit named showed the great proportionate loss of power in hauling the cable where passenger transportation was only of moderate magnitude, and satisfied my mind that for such traffic in cities only slightly undulating it was not the best nor the cheapest mode of applying power.

For a dozen years before electricity was successfully applied to street motors in Europe, my belief and spoken predictions were, that electricity would solve the problem of city transit, and when the first road, commercially operated in this country by this instrumentality, began to be run, a special journey of a few hundred miles gave me the satisfaction of enjoying its novelty. When we note the marvelous increase in this country of electric roads, jumping in a single decade from nothing to the present extensive mileage, and think of the immense capital, and the numbers of people employed, and of the many brains devising ingenious improvements, we can hope for great advances, if not for perfection, by this method of transit for cities, whether located on plains or hills. Perfection will not be obtained, however, by overhead trolleys.

While trials were being made with an electrical motor upon the Ninth Avenue Elevated Railway, an objection was made that was well taken, viz., the running by electricity taken from a conductor pre-

vented independent action of the motors employed. Let the power-house or the conductor become disabled, and all the motors working from that conductor would be useless. A similar objection applies to cable roads. This is partly offset by the great economy in developing power from one set of boilers instead of from many.

As to compressed air, we know of its advantages in underground works, and on some roads so located it may prove a competitor with electricity.

In regard to the compressed steam motors mentioned by Major Sears, doubtless such will find their places. As yet we know little of them practically; may we learn more. The results indicated are interesting, and show the desirability of trials in the presence of expert engineers.

ARTHUR P. DODGE, Esq.—I did not come here to make an address, but, at the suggestion of Major Sears and on invitation, I am very glad of this opportunity to explain, as well as I am able, such details relating to the Kinetic Motive Power system as you may desire to enquire about.

The Kinetic Motor is the outcome of many years of study and work. It is the logical evolution and development of the more or less crude hot water and steam storage power motors in use or on trial some years ago in New Orleans, and which were not then found successful, at least in a commercial sense. Motors having a similar principle of power have been, and now are, in use in France and elsewhere. They are generally of the type known as the Lamm-Franco Fireless Locomotive. This system was first introduced by Dr. Lamm, at New Orleans, in 1872, and the first engines or motors on this principle were started in operation in 1874. Dr. Lamm died soon after. In 1874–75, M. Lion Francq, of Paris, built a motor on this principle, having numerous improvements. It was soon after this that the late Eugene H. Angamar took up the work, and, after many trials, finally succeeded, in 1879, in reaching notable success with the motor car "Lillie," which was, as was well known at the time, successfully exhibited at Washington, D. C., New York, Boston, Chicago, and elsewhere in 1879–80, and later. This car did not do away entirely with the show of steam, but according to all accounts was smokeless, noiseless, etc. Many improvements have since been made and patented, which, together with the Angamar patents, are owned by the Kinetic Power Company. The improvements

made by Mr. Angamar related chiefly to the unique but simple construction of the storage reservoir, answering to the boiler in the ordinary locomotive, and to the small but effective auxiliary fire-box. Thus he was able to see success where had been former failure. As Major Sears says in reference to the Angamar motor now in Chicago, it has been run heavily loaded, hauling two heavily loaded cars and making 20 miles with but one charge of hot water and steam. On a particular trip I have in mind we had a steam pressure at the start of 165 lbs. and at the end of the trip 135 lbs. of steam pressure. This was a 15-mile trip. At this trial the fuel in the fire-box was 37 lbs. of incandescent anthracite coal, which was about two-thirds consumed during the trip. This fire was not even looked at during the entire trip. A condenser, for condensing the exhaust steam by atmospheric contact, has been since added to this motor in Chicago. Our first care was to thoroughly develop and prove the satisfactory maintenance of adequate energy from the direct storage process to give sure and practical results, then to undertake atmospheric condensation. The latest patents contemplate numerous improvements, such as the eccentric pump to force the condensed steam back into the storage reservoir, etc. The I. H. P. of this particular motor as operated is 43. It weighs about 9 tons loaded. All of the machinery and the storage reservoir are located beneath the car floor. The wheel-base is 6 ft., a little too long we found for the sharpest curves, still the motor readily made all the curves and switches that are made by the cable and horse cars. We ran the motor with a trailer, both fully loaded, several times down through the Washington Tunnel under the Chicago River, having an east grade of about 9% and a west grade of about 7. We put the motor to every test we thought of and that the railroad management suggested. We are now arranging to begin the manufacture of the motors in several different forms.

In the use of these motors there is no perceptible noise; previous to the application of the condensers there was a muffled, puffing sound, though in no sense a disagreeable one; now there is no noise whatever from the exhaust.

A record of the tests made in Chicago is as follows:

1. April 23d, 1892.—Ran the motor, hauling one long trailer, four round trips on West Madison Street from Western Avenue to West 40th Street; total distance, 16 miles; running on Western Avenue and

Lake Street, 2 miles, making in all 18 miles. Length of time running, including stops, three hours; coal consumed, 100 lbs.; water evaporated, 100 galls.; passengers carried, 84; steam pressure at start varied from 130 to 145 lbs.; steam pressure at finish, 100 lbs.

2. April 25th, 1892.—Ran motor with one similar trailer two round trips as above, making 8 miles, and running on Western Avenue and Lake Street, 1 mile. Total run, 9 miles; duration of run, including stops, three hours; coal consumed, 100 lbs.; water evaporated, 80 galls.; steam pressure at start, 155 to 130 lbs.; at West 40th Street steam blew off at the safety valve, at 200 lbs. pressure, due to the detention of motor without work (safety or pop valve has since been set at 170 lbs.); other pressures indicated during the trip 165, 135, 175, 180, 175, and at end of trip, 180 lbs.; carried 60 passengers on motor and trailer.

3. May 2d, 1892.—Ran motor, hauling one trailer, both well loaded with passengers, from Western Avenue, on West Madison Street, to West 40th Street; thence to State Street and around the loop; thence back to West 40th Street; thence to Western Avenue and Lake Street, etc., making total length of run 16 miles. Started at 11.30 A.M., ending at 2.30 P.M. Duration of run, three hours; made Madison Street Bridge grade with perfect ease; steam pressure at start, 140 to 130 lbs.; arrived at car shop at end of trip with a steam pressure of 155 lbs. Running time from West 40th Street to State Street, 35 minutes; and from State to West 40th Street, including stops to take and drop passengers, 32 minutes. Conductors took up fares on this occasion, and nearly every time the motor was run. Total fuel, wholly or partly consumed, 100 lbs.; water evaporated, 80 galls.

4. May 4th, 1892.—Left Western Avenue at 12 midnight, with 150 lbs. steam pressure, for West 40th Street, where we took one long trailer, and left at 12.30 A.M. for and around State Street loop, on starting, had 175 lbs. steam pressure, and at State Street had 155 lbs.; thence to Western Avenue, where we made a Y on very poor switches and curves; thence made two more round trips to State Street and around the loop, steam pressure varying and indicating 150, 145, 155, and at the end of running, 105 lbs. the lowest pressure shown on the steam gauge; length of run, 23 miles; duration, including stops, five hours; fuel consumed, 128 lbs.; water evaporated, 130 galls.; large loads of passengers carried; conductors took fares for the company as usual. These trips occurred in the midst of a terrible blizzard

of wind and rain; the west-side tracks were mostly flooded with water, and a more disagreeable or trying night is rarely, if ever, experienced. These unfavorable conditions and all other conditions under which the motor has worked, all far from favorable, have shown that the motor has great efficiency and endurance.

5. May 25th, 1892, 11.55 P.M.—Started motor, with one long 9-ft. wheel base trailer from Rockwell Street Cable Power-House, with a steam pressure of 170 lbs. Proceeded east on West Madison Street, through the Washington Tunnel under the Chicago River, and around the regular La Salle Street Cable Loop, returning to the power-house at 12.55 A.M., having then a steam pressure of 145 lbs. Length of trip, 7 miles. Could have duplicated this trip once certainly, and probably twice upon the one charging. Water level in motor reservoir lowered by evaporation, $1\frac{3}{4}$ ins. Fuel in fire-box, 26 lbs., only about half consumed.

6. May 26th, 1892, 8.40 P.M.—Started from the Rockwell power-house, with similar trailer; steam pressure, 165 lbs. Proceeded east on West Madison Street to and through said tunnel and loop; thence west on said West Madison Street to West 40th Street and through the cable loop house; thence to the power-house, where the trailer was dropped; thence to Western Avenue and Van Buren Street; thence north on Western Avenue, making a Y; thence again to the power-house, arriving at 10.35 P.M., the steam gauge showing 135 lbs. pressure. Water charge lowered in the motor reservoir by evaporation of steam for cylinders, 3 ins. Fuel consumed, 37 lbs. Length of this trip, 15 miles with 45 stops. Carried conductors and passengers these last two trips; both cars crowded.

The West Chicago Street Railroad Company had a connection made with their Rockwell power-house boilers for charging the motor. Said connection was made with the feed pipe at the extreme bottom of said boilers, which gave the motor the sediment and dirt from the large bank of boilers. There were no proper means of preparing the incandescent anthracite coal for motor fire-box. These, with other imperfections, constituted exceedingly unfavorable conditions, notwithstanding which the motor accomplished the foregoing and also many other equally excellent results of which no record was kept. At times we ran the motor every day for a week or more.

CHARLES E. EMERY, M. Am. Soc. C. E.—I am a steam man and I am

sure I like anything that will advance the steam engine. It is still practically the original source of power where reliable water-power is not available, and if a steam locomotive is not at the head of a train it will generally be found hauling the cable or developing the electric current which moves the trains. The use of modified steam locomotives for propelling street cars will be a boon if it can be accomplished. If the old principle of storage of heat in hot water in connection with fire can be made of greater benefit than the former alone we should encourage it. Its application in the streets of Chicago, having only low grades, is quite a different matter from going through streets like those of Baltimore and Brooklyn, which have very many heavy grades on which very great power must be exerted. For such roads the firing features of the hot-water locomotive would necessarily be very prominent, and in the end we would have the steam locomotive improved only by the condenser to reduce the noise, but still a steam locomotive with its weight, grease and some noise at least; but if the people will stand it, the improvement will be welcome.

W. H. Breithaupt, M. Am. Soc. C. E.—I would like to ask to what extent the gravity traction principle is now used. What makes me think of it, I listened to a very interesting paper about three years ago, prepared by a Kansas City cable railway man; he had made a thorough examination of street railroad systems, and found that gravity traction was the best system practicable then in use where the grade was not greater than 10%; above that gravity traction was not practicable. I would ask what improvement, if any, has been made in that respect—whether any better results are obtained?

Mr. Emery.—The revival of electric roads, which gave us the present system, was made in Richmond by Colonel Sprague. He had grades varying from 10 to 14% to overcome. Originally single reduction motors were tried, but they were changed to double reduction, and the road was successfully operated. On those very heavy grades we would, as engineers, of course rather go to the cable, as the grade can then be almost anything we like; but they are now running even single reduction motors regularly on 4% grades.

Mr. Dodge.—What is the weight of those motors making the high grades?

Mr. Emery.—The motors and truck weight about 7 000 to 9 000 lbs., but the whole weight of the car is available for traction, such weight being say 15 000 to 20 000 lbs.

Mr. Dodge.—Some locomotive companies, I understand, are advocating increasing the weight of their motor cars from 6 to 7 tons or less to 10 or 12 tons. Kinetic motors can be constructed of most any weight from, say, 5 to 15 tons and upwards if required, according to power and capacity requirements. Tractive power depends largely upon the weight adequate for the load, grade, etc., in any particular case.

One of the great points of this system of the storage of latent steam is in the fact that the power is generated in stationary boilers, where the benefits of slow, economic combustion are realized; another point is this, that instead of carrying crude fuel and water on the motor, we carry the prepared products of those power elements without the reconversion and transmission losses. Hence, if it be true, as I have said, that we do away with all noise and show of steam, smoke, cinders and dirt, it being clear that our system of power is the most direct in application and therefore most economical, it certainly seems not too much to claim that it is the best and will be proven the most practicable for ordinary street traffic.

The wearing parts of the Kinetic motor are of the simple link motion engine.

Alfred F. Sears, M. Am. Soc. C.E.—With the Sprague system and with two 15-H. P. motors on our cars—we had one 7% grade—we found it impracticable to haul a trailer over our grades.

Mr. Emery.—My recollection is that the Baltimore and Ohio Road ran over a 10% grade on a temporary road, with an ordinary locomotive and one car, while building a tunnel. It will be of interest to add to the general discussion of the subject of electric locomotives, the fact that on the Neversink Mountain Road near Reading, Pa., electric cars weighing empty 22 000 lbs. are propelled with 80 passengers at the rate of 9½ miles per hour up 3.6% grades with two 25-H. P. motors developing at the time about 35 H. P. A report of the tests made under the direction of Dr. Duncan, of the Johns Hopkins University, will be found in a recent number of the *Electrical World*.

E. E. Russell Tratman, Assoc. M. Am. Soc. C. E.—In South America there are several long lines of horse railways similar to the Mexican line referred to by Mr. Sears. Such a line is the "Tramway Rural," extending from Buenos Ayres 250 miles, and having very light grades. Horse-power is employed for the reason that, while coal

costs about $11 per ton, a good horse can be purchased for $20, and kept nearly a year for $20 more. The horses are changed frequently during the trip, which occupies three days, and the fare is $50. The rolling stock equipment includes sleeping cars built by the J. W. Brill Company, of Philadelphia, Pa., which in appearance resemble ordinary four-wheel street cars, but have four upper and four lower berths, toilet room, etc. Such railways, however, are better described as tramways than as street railways.

For city lines with heavy traffic cable traction presents many advantages and has proved very successful. As to the practicability of electric traction there can be no doubt, but there are many objections to the use of overhead wires in city streets. Both storage battery and conduit systems have been proved practicable, but they have not yet been made generally reliable and successful from a commercial point of view, although there is little doubt that this can and will be done. This very desirable result will not be brought about, however, so long as city authorities permit the use of overhead wires, thus cheapening the original outlay.

Both cable and electric systems have the disadvantage of requiring an expensive stationary power plant, and (except where storage batteries are used) a special construction of track, and this renders them undesirable, or even out of the question, under certain circumstances. Among other motors tried may be named compressed-air engines, the Lamm-Francq fireless locomotives (in use on a suburban railway in Paris), and soda motors of the Hinigmann and other patents. There is also an ammonia motor which has been tried at Chicago; and several different forms of steam, petroleum, naphtha and gasoline motors are all on the market. For lines on which the traffic is small or intermittent in character, the question of first cost is very important; and although the overhead wire electric system seems now to be in favor for such lines, the cost of power plant and wiring is a considerable item. For such lines steam traction presents many advantages. Very frequently the track on such lines is too light, and the engines are of light and cheap construction, and are not properly handled, so that they become very dirty and a nuisance generally. This accounts for the prejudice existing against them.

Street motors are generally carried on four wheels, all coupled, and are given to lurching owing to the short wheel base, but some are built

with a leading or trailing pony truck (or both), and are preferable where large and fast engines are required. There are about 400 of these steam motors in operation in this country; and Great Britain has about 550, working in and near large cities and through the neighboring manufacturing districts, some companies having 25 to 75 engines. It must be admitted that they have given rise to considerable complaint in England, owing largely to faulty construction of the earlier engines and their inability to meet the rigid requirements of the Board of Trade as to noise, stopping and starting, emission of smoke and steam, etc.; but some works now turn out very satisfactory engines. Having occasion some time since to report upon the most desirable system for use at a summer resort I made extensive enquiries as to the use of steam motors, and received such favorable opinions that I decided against the overhead wire system on account of large first cost, and the cost of maintenance. My recommendation was that noiseless steam motors (or combination steam-cars) be used, as involving a minimum in both the items named. Steam motors are also extensively used in Italy, Belgium, India and elsewhere for suburban lines and country tramways.

The engines are principally those made by the Baldwin Locomotive Works, of Philadelphia, and H. K. Porter & Co., of Pittsburgh, and the following notes are taken from the information thus obtained. The Baldwin Locomotive Works have also built one or two steam motors on the Vauclain four-cylinder type.

Ensley, Ala.—Engine with cylinders 12 x 16 ins., and weighing 38 000 lbs., hauled 125 000 lbs. on grade of 2%, and around curves of 57 ft. radius. The cars weighed 14 000 lbs. empty, and had seating capacity for 100 passengers. The length of road was 7¾ miles and the engine mileage 124 and 170 miles on alternate days, with a consumption of 3 000 lbs. of coke for the latter distance. The engines were noiseless and very satisfactory.

Selma, Ala.—Engine with cylinders 6 x 10 ins., and weighing 7 tons. Maximum grade, two per cent. The exhaust was noiseless. The engine consumed about 400 lbs. of coke per ten hours, and cost $1 per day for coke and oil. It could stop in 6 ft. at 6 miles an hour and started easily. Engineman's pay, 30 cents per hour.

Nashville, Tenn.—Four-wheel engine, with 36-in. wheel, cylinders 12 x 24 ins., and weight 33 000 lbs. Track laid in middle of business

streets. No accidents and no trouble from frightening horses or from noise. Maximum grade, 8.25 per cent. The engine hauled two 34-ft. cars (sometimes with 300 people), without trouble, and could stop and start on this grade. Engines entirely satisfactory.

St. Louis, Mo.—Engine, 15 ft. long, with cylinders 9½ x 14 ins.; 30-in. driving wheels; 5 ft. 3 in. wheel-base; weight, 20 000 lbs., and burning gas-house coke. Hauled about 45 tons on 3% grades and sharp curves, taking five open cars, with 70 passengers each, at 15 to 20 miles per hour, on runs of 3½ to 6 miles, with frequent stops. Very slight noise from exhaust, and no steam visible except in very damp weather.

Philadelphia, Pa.—Steam car with vertical boiler, 15 H. P. engine and toothed gearing, built by the railway company for $2 000 to $2 500. The car seated 30 persons, and had water tanks under the seats. Length of line, 3 miles. The track was laid on the business streets (47-lb. tram rails on 7 x 7-in. timbers), and there were seldom any accidents, although occasionally a strange horse would get scared. At busy times double-deck cars were attached, and 100 to 200 passengers have been carried. Coal consumption, 1 500 lbs. per day of twelve hours. Enginemen were paid $2.90, and conductors $2.50 per day.

Mr. Sears.—I will say concerning the examination made in this paper, that after having built an electric road and operated it, becoming very much disappointed with the results we have obtained, I was desired when I came East to make investigations concerning any new motors and motive power generally upon street railways. On my way East, stopping in Chicago, I had occasion to see some different experiments that were being made there, and at the invitation of the Boston authorities, I witnessed some experiments made with compressed steam motors, to which I have given special attention in this paper.

I have no interest in the machine, but I have in the company that employs it.

I found the experiments in Chicago less noisy than with the ordinary electric cars..

When I began the investigation, which resulted in the paper now under discussion, I was an enquirer ~~engineer~~; I find myself closing the discussion a confirmed advocate of the use of compressed steam, and especially of that application of it perfected by the Kinetic Power Company.

Only two of those who have taken part in the discussion have made suggestions calling in question the accuracy of conclusions announced in the original paper. Analysis of their statements will, I think, be found to sustain these conclusions.

First.—Is the table presented in the remarks of Mr. Brinckerhoff, from the Annual Report of an English line, in which it is shown that steam paid a net revenue of 4.68d., while the cable paid 6.50d. and electricity 5.25d.

Now this suburban locomotive is just the machine that the Kinetic motor is to supplant. If it did not get rid of the load of tender with fuel and cold water, it would be without value; it would not be the Angamar contrivance. The English locomotive spends 6.38d. per car mile for motive power; the Kinetic motor will make its cost less than 1d. The great economy of slow combustion at a properly constructed charging station must be kept in mind. This difference augments the net revenue for steam by the Kinetic motor to 9.98d. against 4.68d. by the ordinary locomotive; 6.50d. by the cable, and 5.25d. by electricity.

Again, the steam locomotive quoted is debited with a permanent way and building cost of 1.55d. per car mile, while the cable and electric lines have to stand but 0.14d. and 0.13d. respectively. The reason is obvious, and the permanent way of the Kinetic motor will cost less than any of those systems; it is a track having about the duty of the electric car without the conductors; nor has it the conductor and cable of the cable line. It seems not too much to deduct for these expenses, what would bring its cost down to that of the horse line, which is 0.52d. But let us call it 0.60d. which it certainly would not exceed, and then we may add to the 9.98d. per mile for net revenue the difference between 1.05d. and 0.60d. or 0.45d., by which the net revenue on the Birmingham steam line would be increased, making the total net revenue for steam 10.43d. per car mile as against 6.50d. for cable, and 5.25d. for electricity.

It is to be noted, that in this instance the steam duty is performed in the suburbs where the population is sparse as compared with the mid-city district.

The streets of Birmingham rise from an elevation of 100 ft. above sea level to 600 ft. It may be safely granted that in the steep sections of the town the cable is, as premised in the original paper, the proper power to use.

It seems a remarkable fact that the storage battery should produce such excellent results in England, while we have not yet been able to develop anything to give equal results. If I were appointed to make an inspection of that company's accounts, I should try to ascertain just what relation the executive officers of the Railroad Company bear to the storage battery system as a speculation. This remark is the result of a pretty intimate acquaintance with British commercial methods.

As to the apprehensions of Dr. Emery concerning the ability of the Kinetic motor to ascend grades, I believe I am partly responsible for them, in having failed to make it plain that this motor car, like the electric car, carries a load of passengers.

The ability to ascend a grade, with either class of motor, is made up of tractile power sufficient to move a weight required for necessary adhesion.

In either system the tractile power is furnished by the motor, the adhesion by the weight made up of the car-weight and its load. Electricity can do nothing at the circumference of a wheel that direct steam will not do; while to reach electricity we must suffer important loss.

In the case of the Mountain Road, near Reading, mentioned by Dr. Emery, there is an acknowledged loss of 15 H. P. out of 50 H. P.

As to the noise on grades, the Kinetic motor is worked with no appreciable sound, in which it forms a remarkable contrast with the groaning of electric cars on steep streets.

It is in the experience of all engineers, who have been much occupied in earthworks, that contractors' locomotives have to haul empty dumping cars into the pit by grades often exceeding 20 per cent.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
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TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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DISCUSSION ON PILE-DRIVING.

(*Continued from page* 172.)*

By GEORGE B. FRANCIS, M. Am. Soc. C. E., and J. FOSTER CROWELL, M. Am. Soc. C. E.

GEORGE B. FRANCIS, M. Am. Soc. C. E.—The discussion on "Pile-Driving," published in the August number of the *Transactions*, shows, to my mind, two things: first, that the formula advocated by Mr. Wellington is not only reliable, but very useful, when the conditions met with are similar to the conditions on which it is based; second, that there is a lamentable lack of uniform practice by engineers and contractors in this feature of engineering.

I have observed with great interest the work of pile-driving, from the standpoint of an engineer, for 18 years in various parts of the country, and have determined for myself the most important points for which preparation should be made. It frequently happens, however,

* See Paper No. 542, Vol. XXVII, page 99.

that a case with some new condition arises which makes me feel that the method adopted is something of an experiment.

It seems to me that the discussion touches lightly on the very common, I might say universal, method of keeping the hammer line attached to the hammer during the fall. This habit or custom is almost a necessity for the cheap and rapid driving of piles, and will be used for a long time to come, and must be taken into consideration by the engineer when determining the supporting power of the pile, and, if possible, some practical way of correcting the formula for it should be found.

There is also another feature connected with this method of driving which should not be overlooked in such formula, and that is the rapid driving. Many more blows can be struck in the same length of time than with a method where the hammer is allowed to go free at each blow, the result being a much less set or grip by the surrounding earth between blows, or, to illustrate by exaggeration, one blow per minute may produce 1 in. penetration, while two blows per minute on the same pile may produce 2 ins. penetration at each blow.

This, of course, affects the result according to the formula, but may not affect the actual value of the pile.

When driving rapidly with the hammer attached to the line, the hoisting engineer endeavors to prevent more line unreeling from the engine drum than is necessary to let the hammer reach the pile, and I have frequently seen, as have others, the hammer caught just before reaching the pile-head; and also after half the blow had been expended.

This practice can easily be avoided, and, of course, should be, if conclusions are to be based on the penetration.

I knew one engine driver who prided himself on his ability to pick a sheet of paper off the head of a pile with the hammer without bruising the paper.

A frequent cause of small penetration per blow is the crookedness of a pile, which permits it to spring when struck, thus taking up a part of the blow. Another cause is the uneven head of the pile, which permits the hammer to strike on one side. Still another, and perhaps the most common cause, is that the pile is set up out of plumb; this is due to the haste and carelessness with which it is placed in position.

A very natural question arises in this discussion, as follows: what percentage of all the piles driven come within the conditions favorable to the application of the formula for bearing load ?

I venture the statement that fully one-half of all the piles driven are driven under some condition which precludes the satisfactory application of the formula.

If, however, one-half of the piles driven come within the range of the formula, the formula is a decided addition to our working data.

On the West Shore Road I remember one case in dispute, as to when the specifications were fulfilled. The piles driven for a small bridge abutment penetrated at the last blow a distance several times greater than that specified in the contract. The engineer in immediate charge held that the contract was not fulfilled. The driving went on, and the next day an engineer higher in authority was purposely present to insist on better driving.

The contractor, however, proved to his own satisfaction and to that of the engineer that the specification was fulfilled, by setting over the piles driven the previous day, and showing, by repeated trials, that he could not budge them the specified amount without several blows. Was the specification fulfilled ?

The size of a pile has much to do with its value, and it should be insisted on that sizes be fully up to the specification.

As all engineers know, pile foundations are adopted when one is uncertain what else to do, and always in the softest and most difficult places.

It frequently happens that a soft stratum overlies rock or a very much harder stratum, and that in such cases the pile acts as a column. Then it becomes quite important that the area of the point be as large as possible; that the pile is quite uniform in size its whole length, and that the point be not sharpened, and also that the pile be not overdriven and split or bruised.

It is seldom that an engineer has the opportunity by digging out around and exposing to view all or nearly all of a driven pile, to see how it has acted and to draw any lessons from the result.

While building a bridge for Newark Avenue, Jersey City, in 1886, under which passes the New Jersey Junction Railroad, I witnessed, as engineer in charge, the driving and digging out of about 14 piles used for the temporary support of a water-pipe. The material in the street was of uncertain character, being composed of refuse, filling, bowlders, etc.

The piles went in hard, some of them requiring as many as 1 200

blows to penetrate 35 ft. Careful watch was kept of each pile and the way it was driven. The foreman was often asked, whether, in his judgment, the piles were brooming or breaking, and always gave a negative answer. Apparently, they were all put in to full depth, and ready to do all that was expected of them. The work of excavating for the railway was then begun, and one after another of the piles was exposed to view.

More than half of them were disabled by being broken short off at points 6 to 10 ft., and more under ground, some broken twice, and the upper part of the pile going down alongside of the broken point, or being driven right into the point, and splitting it in pieces. One pile in particular struck a flat-top boulder 6 ft. under ground, and about 25 ft. of that pile was broomed up and ramified off into the ground in all directions.

This was new experience to me, and I made up my mind then and there that I could not tell when a pile broke or when it was brooming.

The foreman, one of Ross & Sandford's experienced drivers, was equally at sea. Another like experience at Atwell's Avenue bridge in Providence, where the piles were driven for a similar purpose into a clean mortar sand with no stone of any kind in the way, with similar results as regards breaking, has more than ever convinced me that engineers really know very little about what has happened to piles driven in anything but soft bottom, and that many breaks take place of which the men on the driver are unaware.

Other similar results have been experienced when driving piles behind old bridge abutments for temporary support, while renewing masonry on railroads in operation. Instead of using sound spruce piles, as was done in the cases cited above, I prefer to select a hard-wood pile for such purposes, preferably white oak.

Sometimes it is impossible to penetrate with a sounding rod a material through which it is easy to drive piles.

At Kidd's Cove, a point on the West Shore road nearly opposite Poughkeepsie, I once undertook to get some rod soundings in order to determine the length of pile necessary, but with eight men on the handles of the rod, and after repeated trials, the deepest penetration obtained was 7 ft., the clay seeming to stick and gum the rod, so that it could hardly be extracted. A test pile was driven in the same material, which penetrated 70 ft. with perfect ease. This was another surprise, and I have ever since viewed rod soundings with suspicion.

In 1883 I kept a record of some piles, driven for a dock for the Oregon Railway and Navigation Company, at Albina, opposite Portland, Oregon. These piles were large sticks 70 and 80 ft. long, driven 40 ft. into the river silt, and would go from 8 to 15 ins. at the last blow. Later, I saw this same dock loaded with steel rail for the M. P. R. R., piled as closely as possible, 4 ft. high, without apparently settling the piles, a rough estimate of the load on each pile being about 18 tons. These piles were of large diameter, as were all piles used in that locality, it being no uncommon thing to see in a raft many piles that would measure 150 ft. in length, 30 ins. in diameter at the butt, and 12 ins. at the tip, and be as straight as an arrow.

It is to be hoped, for the benefit of some of the younger members of the profession, that some enterprising member will suggest a formula that will determine the amount of lateral resistance a pile is good for when driven in soft and moderately stiff earths. The formula should be arranged to always give zero as the answer.

If there is one mistake more than any other made in the use of a pile, it is to place on it a vertical load, and in addition make a retaining wall out of it. There seems to be a current opinion that piles in any material are good for either vertical or lateral pressure, and abutment after abutment is built without spur piles or heavy rip-rap, only to fall over or get out of shape. I am not free from guilt on this point myself, but in recent years I have tried to make amends by putting the money required to repair and rebuild an abutment thus built, into rip-rap and spur piles at the start.

J. Foster Crowell, M. Am. Soc. C. E.—Before replying to the points raised by the several gentlemen in the discussion on my recent paper a word of explanation is necessary. In this discussion as printed, see pages 160–161, I appear to have replied already to Mr. Wellington and Mr. Trautwine, but the fact is that these are the verbal and extemporaneous comments made when the paper was read; since then each of these gentlemen has very properly and kindly elaborated and extended his discussion, but owing to my absence from New York at the time they had corrected their proofs and to the editorial necessity for the publication of the paper and the discussion in the August number, I was not able to even see what they had written until too late to add my replies. The following brief comments will therefore

be considered in the light of closing the discussion and not as reopening it.

Had it not been for the absence above referred to, Mr. Trautwine's misapprehension in regard to what he terms the two "Crowell" formulas would have been corrected before it got into these pages, where, of course without intention on his part, it does some injustice to the avowed object of the paper to simplify the list of formulas and not to add to it. In his discussion it would appear as if I had put forth and laid claim to two alternate forms, one of which, designated by him "Crowell (a)," by making use of a universal constant, is a distinct contradiction of the principle of the other, and, with that keen and incisive sense of humor which all admire, he has turned the tables in a way which, if he could find support for it in the original paper, would force a somewhat ridiculous conclusion. But if he will kindly turn to page 106 he will find the following two references (and only these in the entire paper) to the form which he has dubbed "Crowell (a)," to wit: "in order to show graphically the effect of the constant "c" in the *Engineering News* formula and to prepare for reference further on to a suggested modification of this (*i. e.*, the *Engineering News*) formula, the curve, shown by the full line, of the equation $L = \frac{w \times 2h}{s + (c = 0.3)}$ has been introduced," and again "second, the *Engineering News* functions with constant ($c = 1$) give values more and more conservative, comparatively, as the values of s become smaller, whereas, the curve with c taken at 0.3 while growing conservative as s becomes greater, maintains more nearly an average of the other two where s is smaller."

Further on, page 109, although the formula is not again referred to, he will see that mention is made of "the two curves of this (the *Engineering News*) formula in Diagram 2, which we have considered."

Turning back to page 108, will be found a very explicit statement of what the author did offer as his humble contribution and "as the only feature in this paper for which originality is claimed, a development of the (still the *Engineering News*) formula which lends itself in a very elastic and consistent manner to the desired end" (*i. e.*, as the context shows, the rational modification between defined limits of the *Engineering News* formula), which the writer, rightly or wrongly, considered too rigid in its simpler form for universal application. Therein

lies the unpardonable sin, according to Mr. Wellington, whose criticism shall presently be considered, of "tampering with the constant."

It is entirely correct to charge the writer with all the consequences, evil or otherwise, of the proposed modification, but it certainly is not fair to Mr. Wellington, nor to the paper, to designate the modified formula as "Crowell (*b*)," and Mr. Trautwine's very valuable discussion should be read with a hiatus on pages 139 and 143, and on the diagrams on pages 141 and 147, wherein "Crowell (*a*)" appears.

One more correction appears necessary. Mr. Trautwine has considered that the scale of values of n', according to duty classification in Table I, page 110, is offered as an exhaustive and arbitrary one, but a careful reading of the much more modest claims than that, which are to be found on page 112, and in the concluding paragraph of the paper, will show very clearly that the author considered it tentative and illustrative, although he was and is free to say that for usual conditions he thinks it will be found entirely suitable, and consistent with security and economy. By reference to Comparison Diagram No. 3, on page 113, which was not shown when the paper was read, it will be seen that the effect of the variable denominator is on the side of safety for all penetrations greater than 3¼ ins. under a blow of 40 000 foot pounds, while the encroachments on the factor of 6 are within the region of smaller penetrations and light service.

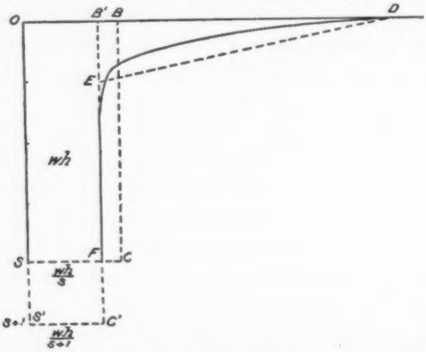
The author desires to thank Mr. Trautwine afresh for his most useful contribution of tabulated results, which adds so very materially to the value of the paper.

Mr. Wellington's discussion is so comprehensive and original that there is more of favor to acknowledge than opportunity for rejoinder. He deserves the thanks of all for his presentation, as a discussion of a paper intended to be very general, of so much that, to quote his own words, "would perhaps be more appropriate in the form of a separate paper," and great credit for his very able and thorough treatment of the subject, especially of the part relating to the consideration of the frictional resistance of piles.

Mr. Wellington devotes five pages to the derivation of the constant 1, as applied to the *Engineering News* formula, and two pages more to reasons why it should not, as he says, be "tampered" with or, in another place, "monkeyed with." Although Mr. Wellington is far too polite to say so, he intimates that a "fool has rushed in where angels

fear to tread," and he certainly has made a brave fight for the integrity of his constant. The author having approved his formula has not pleased him thereby nearly so much as he has exercised him later by "improving."

As to the infallibility of the constant 1, Mr. Wellington has, apparently, himself provided the strongest kind of a doubt, in his demonstration on pages 133 and 134, for he says: "I assume that the decreasing excess resistance outlined by the line $E\,D$ (referring to the diagram on page 132, which is here reprinted for convenience) and whose value in



foot pounds is expressed by the irregular area $B'\ ED$, is confined within the first inch of penetration (*i. e.*, that $B'\,E = 1$), and that the initial excess $B'\,D = 3\ o\ B' = 3\ s\ F$. The selection of these particular constants instead of others a little higher or lower is pure assumption in the sense that we can never know experimentally just how this is." Then follow his reasons for the assumptions, and, next, an entirely correct and very ingenious demonstration, based upon the first assumption (*viz.*: that the portion of the set of the pile, under the blow, in which the resistances are excessive, is within the first inch of penetration) that $wh = R \times (s + 1)$ *q. e. d.* But what occurs when there is no first inch? Obviously when the entire set is 1 in. or less, the value to be assigned to $B'E$ must be some fractional part of 1. Now, it is a natural consequence of Mr. Wellington's demonstration, which can be verified by simple substitution, that whatever value be assigned to $B'E$ will necessarily be the value to be added to s. In other words, his value c, instead of being constant for all values of s, must be a variable and equal in each case to the assumed value for $B'E$: this is an exact

result according to Mr. Wellington's own figures, using his equations without change or taking any liberties with his value of the initial excess of resistance, which is independent of the penetration.

In every case where s is less than 1 in., and in some cases even where it exceeds 1, $B' E$ a part of s must be smaller than 1. In the very ordinary cases where s is, say, $\frac{1}{2}$ or $\frac{3}{8}$ of an inch, $B' E$ might be as small as $\frac{1}{4}$ of an inch and the value of Mr. Wellington's precious "constant" would also be one-fourth.

In other words, Mr. Wellington has unwittingly demonstrated that his increment of the denominator of his formula must vary with the penetration. The modification proposed by the author takes account of this very obvious variation and seeks to adjust it by reference to a standard blow applied in the natural course to each pile before the termination of the driving.

But apart from this demonstration let us consider practically what is the actual effect of the presence of the constant 1, around whose slender form Mr. Wellington has drawn such an "awful circle." We might construct a curve which would show its inconsistencies through a wide range of driving, but one or two examples will suffice.

Let us suppose a case where a pile is being driven in soft material and where the penetration is considerable; one of the cases in Lake Pontchartrain, cited by Colonel Nicholson (see page 157), where, after driving 100 ft., the penetration was 9 ins.; the working load of that pile by the Wellington formula would be $\frac{2\,wh}{9+1} = \frac{2}{10}\,wh$, and the effect of the constant is to reduce the loading from $\frac{1}{9}$ to $\frac{1}{10}$ equivalent to 11 per cent. With such great penetration we should, of course, be on our guard, and common sense would cause us to make a much greater allowance. Now, let us take another case where a pile had been driven through firm material for, say 30 ft., and the last blow showed a penetration of $\frac{1}{2}$ of an inch. Here, obviously, the conditions are very favorable and we might rest assured that the pile was trustworthy, but the effect of the constant 1 would be to reduce the loading by $66\frac{2}{3}$ per cent.

Again, let us suppose that in the same work are two piles side by side, but one much larger in diameter than the other; let us assume that No. 1 under the last blow has penetrated 1 in., but that the other, being larger, has only penetrated half an inch under an equal

blow. Practically, we should be justified in the conclusion that No. 2 would sustain twice (or more than twice) as much as the other, but by the Wellington formula the presence of the constant would give in the first case $L = \frac{2\ wh}{1+1} = wh$, and in the second $L = \frac{2\ wh}{\frac{1}{2}+1} =$ 1.33 wh.

Here, as in the other case, we must vary the "constant"; in fact, we must "tamper" with it, to make it useful and reliable. Mr. Wellington further alleges that differences of 10 to 12% of loading, *i. e.*, when they are against his formula, are "small differences to dispute over." In this I cannot agree with him, but must maintain that such differences in cost of a foundation are well worth saving and, as shown in Comparison Diagram No. 3, they must be often greater and on the other side. Nor can I concur when he declares that the allowance to be made in important structures should not be made in a formula, but that "the way to make such changes is to space the piles a little nearer together or farther apart than we otherwise would," which, besides being a clumsy and often undesirable thing to do, has no bearing whatever on the value of a formula whose use consists in arriving at the bearing power of the separate piles as they are driven, and so to determine whether they shall be driven closer together or not so close. But while Mr. Wellington's demonstration is of no service whatever in determining the increment of the denominator, it is quite apparent that his ingenious treatment of the subject suggests a way of obtaining data for determining it still more closely than the author deems it possible to do with his own proposed standard blow. If Mr. Wellington will marshall the array of extensive observations of the behavior of piles in driving to which he has referred, he doubtless will be able to afford us much additional light on the ratio of the allowance for "c" in terms of the ram energy divided by the penetration; "here all the honor lies."

Mr. Wellington offers what he terms a further reason why the constant 1 should not be tampered with, which is briefly stated, that with it his formula reduces to $L = 2\ wh$ when $s = 0$, *i.e.*, when the pile has been driven to solid bottom, and can penetrate no farther, "which happens to be just about what the pile can safely carry as a column under ordinary and probable values of w and h," etc. This reasoning may truly be called occult. What is the probable value of w, and from what height does the hammer usually fall when piles strike solid

ground? It seems scarcely necessary to point out that the two things, the strength of the pile as a column and the ram energy expended in driving, are incommensurable and can have no fixed relation to one another, for the very obvious reason that the instant the pile strikes solid ground and penetration ceases, the driving formula becomes inapplicable; there is no transition, but a new condition, for which the column formula must be used. In addition to that, neither w nor h can bear any fixed relation to the solid bottom or to the length of the pile; if we suppose the solid bottom to be a shelving rock nearer to the surface at one part of the work than at another, so that, in the driving, one, of two piles of equal length and same material and diameter, brings up on it with 10 ft. less fall of the hammer, we perceive that —though the strength of the two piles as columns are equal—the product $2\ wh$ in one case is, as compared with the other, only $2\ w\ (h - 10)$; perhaps only one-half as great, or even less dependent, of course, on h.

Again, let us consider the case of a pile of a certain ordinary length and diameter, which has been driven to the point of no penetration under a known value of $2\ wh$. In one locality this pile, probably, would be hemlock, but in another part of the country it probably would be white oak with a very different modulus of crushing, although $2\ wh$ would, under the conditions cited, perhaps, although not probably, be the same.

Finally, let us assume the case of two piles of the same material having an equal ratio of $\frac{1}{d}$, but of different diameters, the larger being selected for the deeper position, and that they, on account of varying depth, can be and are driven home to the solid rock with the same fall; $2\ wh$ is then the same in regard to both, but it cannot "happen to be just about what each pile can safely carry as a column," because the two piles differ in that respect in proportion to their diameters; it is quite within the usual conditions for one pile to be as much as twice the diameter of the other.

The *Engineering News* formula (as stated in the paper) is in the estimation of the writer the best in form and the most reliable, speaking generally and for ordinary cases. But, to make it universally applicable, the denominator must be elastic, and the constant must be displaced by a series of values, corresponding to the varying conditions of driving; a further adjustment of loading should be made ac-

cording to the character of the duty; this is independent of the primary function of the formula, and could be effected by applying a coefficient to the numerator instead of adding a second quantity to the denominator. Mr. Wellington claims that the coefficient is better; practically, as an arithmetical operation, it is largely a matter of individual preference, but the writer considers it better to keep the form of the *Engineering News* formula for the reasons given in the paper, especially (as Mr. Trautwine has noted, page 143) as the increase in complexity is less than might be supposed at first glance. In fact, there is no complexity in the principle when once the objects of the variations are clearly understood.

Mr. Reece is quite correct in his view as to the best time to get final results, although such results as he aims at would be only indicative of general conditions on a special work and could not be usually applied to every pile. But the object treated of in this paper does not extend beyond the pile itself and its behavior under the final blow whenever that blow is administered. He is also unquestionably correct, as are Messrs. Bouscaren and Nicholson, as to the observed fact that, in some soils, piles become more capable of resistance after the lapse of time.

The author desires to thank Mr. Nicholson and other members who have contributed the statistics which add so much to the value of this discussion. Colonel Craighill with his one-man power driver has lightly touched upon a weighty question, which concerns the failure by sinking of pile foundations when subjected to very slight lateral motion.

Mr. Robert B. Stanton is palpably in error when he concludes that "every one seems to have treated the pile as a column resting upon a foundation, which will be reached by this method of driving with a heavy hammer, and the formulas are all made with this as a basis"; as a fact, none of the formulas discussed in this paper have this basis, and, as has been pointed out by Mr. Wellington and the author, piles must be considered as columns and their strength as such taken as the limit whenever the computed net sustaining power by the formula exceeds it. In other cases when the pile is short, its strength as a column may exceed its resistance to fiber crushing. Both these considerations are, however, outside of the field of this discussion, which, as has been reiterated, is confined to the modulus of sustaining power of the pile as gauged by the blow of the ram.

Mr. Brush's discussion is practical and valuable; all that he has said in support of his proposition that the matter of driving piles is one to be treated practically and not theoretically is thoroughly endorsed; not only here, but in the original paper, the author has sought to eliminate all theory, excepting as to the principle on which the effectiveness of a driven pile depends. Unquestionably, as Mr. Brush says, we should wherever possible, take preliminary borings to determine the character of the material to be penetrated, and we should rely on the indications as the work proceeds. But the most definite indications obtainable, and which must be final, are those given by the piles themselves as they are being driven. Of course in many instances test-pits can be sunk, but often the very conditions which force a resort to piling render the test-pit impracticable. This is true in all water-covered sites, in swamps and quicksands and in places where there is a great absence of uniformity. In many cases borings are impracticable, and in any case such examinations are only qualitative: they give no measure of resistance of the soil; this the pile does.

As to the danger of continuing to drive a pile to destruction after it has been driven home, that is most eminently a practical question against which no formula could guard, but it is also a matter of observation and one which the intelligent consideration of the rate of progression of the pile and of its fellows can generally detect.

But to Mr. Brush's closing comment I must take a practical exception; after stating that often we do not apply our common sense, but do apply a formula to a condition which is continually changing, and the result is we drive our piles too hard or not hard enough (which is unquestionably true, and the fact is the basis and the *raison d'être* of the paper under discussion), he adds, in conclusion, "our discussion has been pursued on the basis that we are driving through uniform material." The basis of the discussion, although we may have wandered from it, is that we are to drive through all sorts of materials and in many varying conditions, but desire to obtain consistent and uniform results. The value and importance of securing uniform unit pressures under buildings is conceded; the principle the author contends for extends to pile foundations, and so far as may be to every pile. There is no advantage in having one portion of a foundation rigid if an adjacent portion is yielding; on the contrary, if all cannot be rigid all

had better be uniformly yielding. Again, if the necessary sustentation can be obtained without driving piles many additional feet to "home," it is costly and of no advantage to continue the driving. With a pile and a ram and a standard blow for comparison and a formula, we can practically know, at least relatively, whether each pile is capable of performing its part ; test pits will not show this, nor preliminary borings, nor that most uncertain and misleading of all instruments, the ordinary sounding rod.

In Mr. George B. Francis' very practical and useful discussion are several points which may be briefly answered.

In regard to the very common usage among pile-drivers of keeping the hoisting rope attached to the ram during the fall, it is to be noted that though this unquestionably modifies the fall through the resistances in the winding-drum, it does not follow that the effect must be introduced, as Mr. Francis suggests, into the formula. The simpler way is to cast off the rope when giving test blows ; the pile-driving machine should always be provided (as most of them are) with both friction drum and tripping latch, so that the hammer can be operated in either way.

Rapidity of driving unquestionably affects the amount of penetration, though not perhaps to the extent of Mr. Francis' simile (which he says is exaggerated) but so far as the formula is concerned, this consideration is always on the safe side, and practically in most cases would not add much to the cost of the foundation. The case which he cites of the pile acquiring stability over night has a direct bearing on the question of rapidity of driving. It is not always safe, however, to assume that the conditions will improve with time.

Mr. Francis' poor opinion of the sounding rod as a detecter is fully endorsed, and he correctly states the conclusion that bearing piles should never do duty as a retaining wall.